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Research Article

Response of soil strength and density to compost application: A study on the vegetative phase of pineapple

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Abstract

This study aimed to determine the effects of applying 50 t ha^{-1} of compost, made from a mixture of cow dung, bromelain waste, and chopped bamboo, on soil compaction and penetration in pineapple (*Ananas comosus* L. Merr.) plantations in Central Lampung, Indonesia. This study used a survey method at four locations, each representing a different age of pineapple plants. Soil penetration analysis was performed using a Digital Cone Penetrometer. Soil bulk density and total pore space were determined using the volumetric method. The results indicated that soil compaction decreased with increasing pineapple plant age, corresponding to a reduction in soil bulk density. Specifically, the soil bulk density values for pineapple plants at 0, 3, 5, and 9 months after planting (MAP) were 1.42 g cm^{-3}, 1.23 g cm^{-3}, 1.13 7 g cm^{-3}, and 1.02 g cm^{-3}, respectively. Lower soil bulk density corresponded to less soil compaction, leading to lower soil penetration resistance. The lowest soil penetration value was recorded at location 9 MAP, while other locations remained below the critical soil penetration limit. A lower soil penetration value indicates reduced soil strength. There was a positive correlation between soil bulk density and specific gravity, and between soil penetration and age at 5 and 9 months. Conversely, higher soil pore space and dispersion index were associated with decreased soil penetration. In conclusion, applying 50 t ha^{-1} of compost appears to be an effective solution for pineapple cultivation.

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Introduction

PT. Great Giant Pineapple (GGP) in Central Lampung, Indonesia, is a multinational company that produces fresh pineapples, canned pineapples, fruit juices, and other agricultural products. After intensive crop cultivation for more than 30 years, problems of land degradation and declining soil fertility have emerged, along with the high Cost of Production. In 2020, 53% of PT. GGP's land had an organic C content of less than 1.2%, averaging around 0.97%. Efforts have been made to improve soil fertility by utilizing in-situ organic waste, including cow dung, bromelain waste, pineapple peels, and decanter pulp, as compost, applied at a rate of 50 t ha^{-1}. However, applying 50 t ha^{-1} has not been optimal for improving soil fertility. Research conducted by Cahyono et al. (2020) showed that applying 50 t ha^{-1} of compost can increase soil organic C by only 5%, and this does not persist in the soil. Furthermore, macronutrient availability (N, P, and K) decreased after applying 50 t ha^{-1} of compost. The decline in soil fertility and suboptimal land productivity is caused by high nutrient and organic matter leaching, as well as soil compaction.

In tropical areas, high leaching can cause clay to accumulate in the lower soil layers, making the soil easily compacted and degraded (Umaru et al., 2021). Land degradation is a limiting factor in optimizing crop production because the soil, as a planting medium, does not provide suitable conditions for plant growth (Bindaraban et al., 2012).

Land cultivation on PT. GGP's pineapple plantation uses heavy equipment intensively during both the dry and rainy seasons. The soil's water content will affect compaction. In dry conditions, the pressure that occurs on the soil will not affect compaction. However, the pressure applied to the soil surface in wet conditions will cause compaction, related to increased soil bulk density and total soil pore space (Spoor et al., 2003). The pressure applied to the soil will cause soil aggregates to disintegrate, reducing the total soil pore space and increasing soil compaction (Liu et al., 2023).

Soil compaction, while challenging to detect and rationalize, is a crucial aspect of soil health that demands our understanding. It may not manifest visible signs on the soil surface, but its effects on the physical characteristics of the soil, such as pore space, bulk density, and soil strength, are profound (Keller et al., 2019; Horn et al., 2023). Soil compaction results from compressive forces acting on the soil, increasing particle weight and making the soil more compact (Shaheb et al., 2021). By understanding and addressing soil compaction, we can make significant strides in improving soil health and crop production.

Soil compaction significantly affects plant root growth (Mileunsnic et al., 2022). It increases soil bulk density and strength, making it challenging for roots to penetrate the soil layer (Villalobos and Fereres, 2016). Soil penetration resistance, a reflection of soil strength and ease of root penetration, becomes problematic with increased soil compaction, inhibiting plant root growth (Nawaz et al., 2013). Proper plant root development requires loose soil to facilitate root penetration.

Poor soil physical properties, such as high compaction and penetration, can be improved by compost because organic compost materials can function as ameliorants and soil conditioners. Compost fertilizer comes from organic soil materials decomposed by microorganisms. The organic material content in compost can improve the soil's physical properties and is highly effective in maintaining soil quality (Lal, 2020). In addition to adding nutrients, organic materials also function as ameliorants or soil conditioners, improving soil physical characteristics by acting as adhesives that increase soil aggregation and pore space.

Humic acid contained in cow dung compost can modify and improve soil structure (Purnamasari et al., 2022). In heavy, compact soil, humic acid increases the ability of soil colloids to bind, making the soil sticky and less easily destroyed. It can improve aeration and soil water retention capacity (Cahyono et al., 2020). Organic matter acts as a granulator (forming a granular soil structure) because it contains extracellular mucus from heterotrophic microbes that form a network, like a net, and a gel that can unite and agglomerate soil particles, thereby improving soil structure and soil aggregates, increasing soil porosity and water-binding capacity (Tisdall and Oades, 1982). The higher the compost dose, the lower the soil compaction. The higher the organic matter, the lower the soil bulk density, the increase in the total soil porosity, the improved soil structure, and the reduced soil penetration and compaction. Low penetration indicates low soil compaction (Celik et al., 2004). Therefore, applying 50 t ha^{-1} of a compost mixture of cow dung, bromelain waste, and chopped bamboo can reduce soil compaction and improve soil penetration.

The applied compost will provide the nutrients plants need. Compost releases nutrients slowly and cannot meet nutrient needs during critical periods. Chemical fertilizers are required to provide the nutrients plants need, but long-term use can decrease soil fertility. Efforts to maintain soil quality and meet plant nutrient requirements include applying organic fertilizer (Cahyono et al., 2020). As much as 520-632 kg ha^{-1} of organic fertilizer is needed to replace chemical fertilizers and achieve the desired pineapple yield (Rothé et al., 2019).

This study aimed to determine the effects of 50 t ha^{-1} of compost from a mixture of cow dung, bromelain waste, and chopped bamboo on soil physical properties (compaction and penetration) during the vegetative phase of pineapple (*Ananas comosus* L. Merr.).

Materials and Methods

This study, conducted from December 2022 to January 2024, used a comprehensive survey. Soil samples were taken from PT. Great Giant Pineapple at several locations simultaneously at different pineapple plant ages, namely 1 location at 0 (zero) months after planting (MAP), 5 locations at pineapple age 3 MAP, 5 locations at pineapple age 5 MAP, and 3 locations at pineapple age 9 MAP (Figure 1). Undisturbed soil samples were taken at 3 points on each plot, diagonally, at a depth of 0-20 cm, resulting in 96 soil samples, while disturbed soil samples were taken at 5 points diagonally at the same depth. Then, composite sampling was carried out, yielding 32 soil samples (Table 1 and Figure 1).

Land preparation began by dismantling the remains of the previous pineapple plantation. The pineapple stalks were then chopped into small pieces. This material was thoroughly mixed with the soil during plowing with a mail board, followed by soil aggregate pulverization with a disk flow. Compost was then applied evenly to the soil. This process lasted approximately one month. Pineapples were planted two weeks after the compost was applied. Ridges were then created one day before planting. Compost at a rate of 50 t ha^{-1} was applied to all experimental plots.

Table 1. Soil sample locations.

Location age	Location name	Plot	PG	Coordinate point	Area (aa)
0 MAP	32C	1	1	4°48'11'S and 105°07'03"E	0.76
		2	1	4°48'14'S and 105°07'03"E	0.70
3 MAP	028E	4	1	4°48'3.73"S and 105°14'41.58"E	0.76
		7	1	4°48'34.31"S and 105°14'43.28"E	0.48
	086B	4	1	4°48'7.61"S and 105°10'56.53"E	0.82
		6	1	4°48'5.60"S and 105°10'58.42"E	0.76
	086E	4	1	4°48'37.73"S and 105°14'41.58"E	0.44
		8	1	4°48'6.17"S and 105°10'39.89"E	0.51
	138C	13	2	4°45'49.96"S and 105°4'25.29"E	0.86
		14	2	4°45'48.66"S and 105°4'25.22"E	0.71
	132B	3	2	4°47'3.03"S and 105°5'2.48"E	0.74
		4	2	4°47'3.45"S and 105°5'1.07"E	0.74
5 MAP	027F	4	1	4°48'2.61"S and 105°15'0.55"E	0.63
		7	1	4°47'57.92"S and 105°14'57.18"E	0.76
	094B	4	1	4°48'58.13"S and 105°9'24.52"E	0.87
		6	1	4°48'58.73"S and 105°9'23.83"E	0.62
	113B	4	2	4°48'3.69"S and 105°7'43.32"E	1.5
		11	2	4°48'2.96'S and 105°7'42.01"E	0.61
	123B	10	2	4°47'49.95"S and 105°5'31.20"E	0.59
		11	2	4°47'50.22"S and 105°5'29.87"E	0.61
	125C2	5	2	4°48'54.31"S and 105°5'29.87"E	0.64
		16	1	4°48'37.73"S and 105°14'41.58"E	1.15
9 MAP	33B1	6	1	4°48'54.31"S and 105°16'50.15"E	0.84
		11	1	4°48'48.71"S and 105°16'49.91"E	0.92
	33B2	9	1	4°48'51.67"S and 105°16'49.68"E	0.85
		16	1	4°48'46.14'S and 105°16'49.47"E	0.85
	66L	AB	1	4°49'5.93"S and 105°12'50.36"E	0.60
		CD	1	4°49'7.35"S and 105°12'49.82"E	0.58

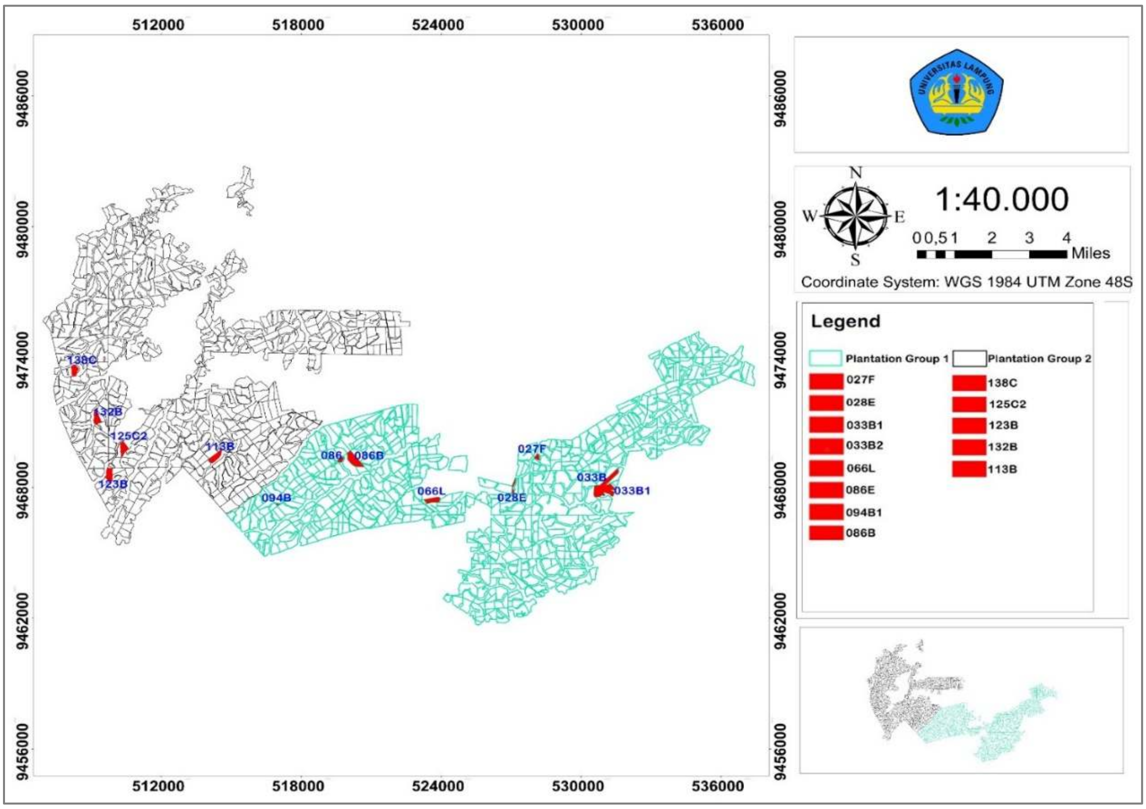

Figure 1. Map of soil sampling in plantation groups 1 and 2 of PT. Great Giant Pineapple, Central Lampung.

Soil physical parameters were observed during the early vegetative phase of pineapple plants at 0, 3, 5, and 9 months after planting.

The compost used in this study was made from cow dung, waste from bromelain production, and chopped bamboo (with a composition 3:1:0.5 ratio). Waste from making bromelain is produced from the pineapple canning industry; bromelain is contained in pineapple stems, leaves, and skin. Composting began by placing the cow dung into a well (10 m in diameter and equipped with a stirrer). Once homogenized, the cow dung was separated into two parts: solid manure, used as compost material, and liquid manure, used to soak the pre-decompost, which consisted of bromelain and bamboo dregs, and was then mixed with the solid manure. The composting composition used a 3:1 ratio, with 3 parts solid manure and 1 part pre-decompost. The material was then placed in a bath and stirred using a tunner for approximately 1 month until the compost matured and was ready to be applied to the soil (Sutanto and Lubis, 2018). The characteristics of cow dung compost are as follows: pH = 7.20, organic C = 21.60%, N = 1.68%), C/N ratio = 12.86, K = 18.13 g kg^{-1}, Ca = 21.50 g kg^{-1}, and Mg = 5.26 g kg^{-1} (Cahyono et al., 2020).

Soil penetration analysis was made using a Digital Cone Penetrometer (DIK-5532i). The penetrometer was pressed with a strong, stable force until the needle reached a depth of 90 cm. When the penetrometer needle could no longer penetrate the soil layer, the measurement was carried out only to the depth at which the penetrometer needle could penetrate. Soil depth was divided into two parts: 0-20 cm and 20-90 cm. Soil bulk density and total pore space were determined using the Volumetric method. For soil that was not too compact or hard and did not contain rocks, intact soil samples (ring samples) were used (FAO, 2006).

The specific gravity of the soil was determined using the pycnometer method (Umaru et al., 2021). The pycnometer method is based on determining the liquid's mass and its occupied volume. The soil samples were oven-dried at 105 °C for ±24 hours, then cooled in a desiccator. The empty pycnometer (W1) was weighed, and ±10 g of dry soil was placed into the pycnometer and weighed (W2). Distilled water was added to ½ the volume, and the mixture was stirred to remove air bubbles. The pycnometer was filled with water, dried on the outside, and weighed (W3). After that, the pycnometer was emptied, filled with water only, and weighed (W4).

The dispersion index was determined using the aggregate dispersion method with water immersion, as proposed by Emerson (1959). The Soil Dispersion Index (DSI) is used to determine a soil's susceptibility to dispersion (i.e., its tendency to decompose in water). Air-dried soil (50 g) was mixed with water without a dispersing agent and shaken gently. The mixture was allowed to settle, and the amount of dispersed fines was measured. Then, the result was compared with the total dispersion result (using a chemical dispersing agent).

Soil texture was determined using the hydrometer method, which involved measuring the soil dispersion ratio (Bouyoucos, 1962). 50 g of fine soil was mixed with water, a dispersant solution was added, and the mixture was shaken with a stirrer for ±10-15 minutes. The soil suspension was poured into a 1,000 mL cylinder, and water was added to the mark. The cylinder was then shaken for ±1 minute and then placed on a table. Next, the hydrometer was read at 40 seconds (sedimented sand fraction) and at 2 hours (suspended silt and clay fractions).

Data analysis was conducted qualitatively by comparing the observation results with existing criteria. The data distribution was displayed using a Box plot, and correlation was tested to determine relationships between variables using IBM SPSS Statistics version 27.

Results and Discussion

Soil aggregate stability and soil texture

Aggregate stability and soil texture affect soil density; less stable soil aggregates are more easily destroyed, thereby reducing pore space and increasing soil density. Aggregate stability is influenced by soil texture. This study found that soil with a clay texture was rapidly destroyed when exposed to water (Table 2). All locations showed that soil aggregates were in the unstable category, but at 9 MAP, one location had very stable aggregates. The organic material in compost functions as a soil conditioner, acting as an adhesive for soil particles and improving soil aggregation. Organic material acts as a granulator (formation of granular soil structures) because it contains heterotrophic microbial extracellular mucus that forms a gel network that can unite and clump soil particles, which will be able to improve soil structure, increase soil porosity, and water binding capacity so that it will reduce soil penetration and compaction (Widodo and Kusuma, 2018). Soil texture significantly affects soil compaction. The type of soil texture at each location is shown in Table 3.

The results of the soil texture analysis (Table 3) showed that location 0 MAP was dominated by sandy clay. In contrast, locations 3 and 5 MAP were dominated by sandy clay loam and sandy clay, respectively, while location 9 MAP was dominated by sandy clay loam. The results are in line with Holilullah et al. (2015), who reported that the soil texture at PT. Great Giant Pineapple is sandy clay and sandy clay loam. The sandy clay soil texture at locations 0 and 3 MAP can make the soil easily compacted. When wet, soil with a high clay content easily disperses into mud, and when dry, it quickly hardens. In this process, the dispersed soil will clog pores, increasing bulk weight and decreasing soil infiltration (Syafruddin, 2007; Syaifuddin and Buhaerah, 2010).

Table 2. Soil aggregate stability values and categories at each pineapple plant location age.

Location Age	Location Name	Plot	Aggregate Stability Index	Value Aggregate Stability
0 MAP	032C		19.23	Unstable
3 MAP	028E	4	17.54	Unstable
		7	17.54	Unstable
	086B	4	15.87	Unstable
		6	16.67	Unstable
	086E	4	16.13	Unstable
		8	18.18	Unstable
	138C	13	31.25	Unstable
		14	27.78	Unstable
	132B	3	23.81	Unstable
		4	18.52	Unstable
5 MAP	027F	4	14.29	Unstable
		7	17.24	Unstable
	094B	4	22.22	Unstable
		6	27.03	Unstable
	113B	4	17.24	Unstable
		11	16.95	Unstable
	125C2	10	19.61	Unstable
		11	16.13	Unstable
	123B	5	17.24	Unstable
		16	17.24	Unstable
9 MAP	33B1	6	28.57	Unstable
		11	41.67	Moderately stable
	33B2	9	200	Very Stable
		16	30.30	Unstable
	066L	AB	20.83	Unstable
		CD	15.63	Unstable

Table 3. Soil particle-size distribution and texture at each pineapple plant location by age.

Location Age	Location Name	Plot	Sand (%)	Silt (%)	Clay (%)	Soil Texture
0 MAP	32C	1	69.47	5.08	25.45	Sandy clay loam
		2	54.17	9.65	36.17	Sandy clay
		4	59.26	2.88	35.83	Sandy clay
		6	59.25	4.32	36.23	Sandy clay
3 MAP	028E	4	60.89	4.6	32.74	Sandy clay loam
		7	74.32	4.7	20.98	Sandy clay loam
	086B	4	66.14	8.71	24.70	Sandy clay loam
		6	71.67	5.14	23.17	Sandy clay loam
	086E	4	62.92	6.95	30.12	Sandy clay loam
		8	60.64	7.46	31.94	Sandy clay loam
	138C	13	49.02	5.35	45.48	Sandy clay
		14	41.42	12.3	46.23	Sandy clay
	132B	3	49.17	10.7	40.12	Sandy clay
		4	46.55	8.43	45.12	Sandy clay
5 MAP	027F	4	51.61	6.45	41.94	Sandy clay
		7	62.80	9.66	27.54	Sandy clay loam
	094B	4	41.31	22.3	36.34	Sandy loam
		6	55.48	7.86	36.7	Sandy clay
	113B	4	66.16	6.15	27.68	Sandy clay loam
		11	65.55	5.74	28.71	Sandy clay loam
	125C2	10	76.21	7.92	15.85	Sandy loam
		11	59.26	5.43	35.31	Sandy clay
	123B	5	63.56	5.60	30.84	Sandy clay loam
		16	60.62	5.62	33.72	Sandy clay loam
9 MAP	33B1	6	57.74	9.81	32.71	Sandy clay loam
		11	62.82	8.58	28.56	Sandy clay loam
	33B2	9	67.93	9.85	22.18	Sandy clay loam
		16	54.84	9.68	35.48	Sandy clay loam
	66L	AB	63.80	2.87	34.43	Sandy clay loam
		CDK	55.82	11.0	33.14	Sandy clay loam

Soil bulk density, soil pore space, soil specific gravity, and dispersion index

Unstable soil aggregates with a clay-dominated texture will increase bulk density and specific gravity and decrease pore space. The higher the bulk density, the less the pore space; the more compacted the soil, the higher the soil compaction. Compacted soil has more particles per unit volume than soil with low bulk density. The bulk density and specific gravity of the soil decreased with increasing age of the pineapple plant, while the total pore space and soil dispersion index increased with increasing age of the pineapple plant (Figure 2). The soil bulk density at location 0 MAP was in the very high category; at location 3 MAP, it was in the high category; and at locations 5 and 9, it was in the moderate category. The decrease in soil bulk density from location 0 MAP to location 3 MAP was 13.3%, from location 3 MAP to 5 MAP is 4.8%, and from location 5 MAP to 9 MAP was 12.8%.

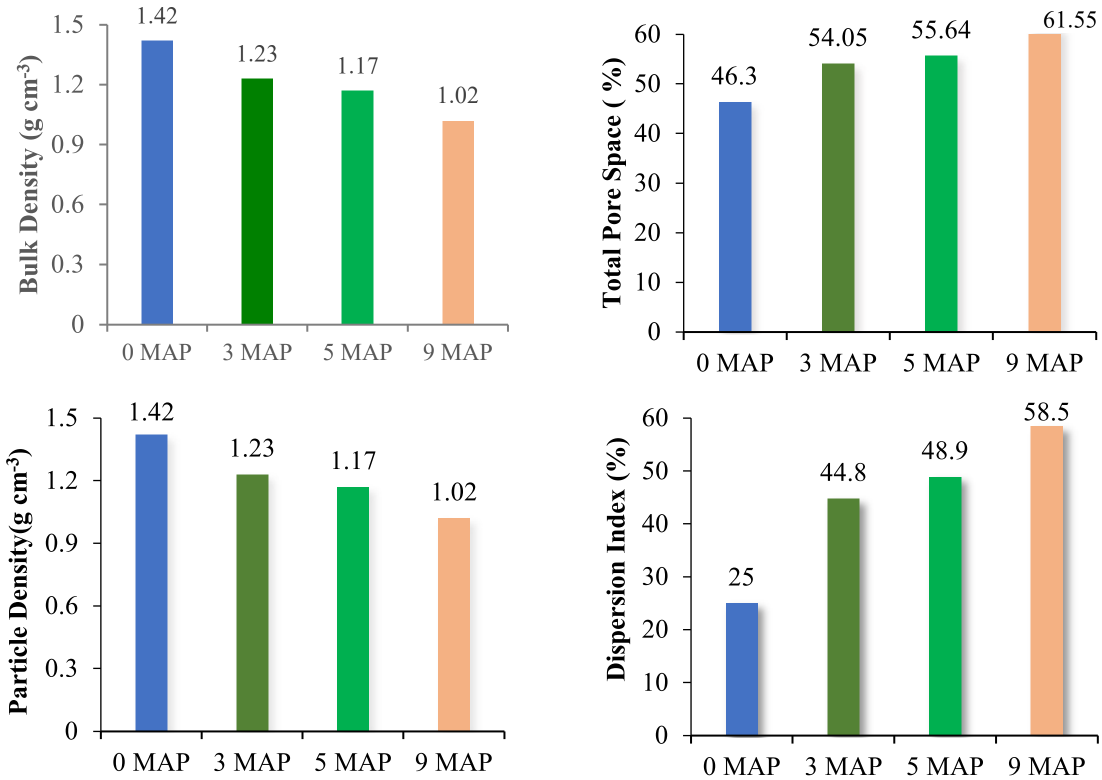

Figure 2. Soil physical properties values at each pineapple location age.

Soil pore space at location 0 MAP was in the medium category, at locations 3 and 5 MAP was in the high category, and at location 9 MAP was 61.23% in the medium category. The decrease in soil pore space value from location 0 MAP to location 3 MAP was 13.01%; from location 3 MAP to 5 MAP was 4.78%; from location 5 MAP to 9 MAP was 9.82%. Compared to other locations, the low bulk density value and high total pore space at the 9 MAP pineapple plant age were influenced by the organic matter content, whereas the 9 MAP pineapple plant location had a higher organic matter content (Maula et al., 2024). The effects of organic matter concentration on soil bulk density show that it consistently decreases with increasing organic matter concentration, due to increased soil volume (Trisno et al., 2016). The soil's bulk density and total pore space are closely related to soil compaction. The results are based on Umaru et al. (2021), who found that higher bulk density is associated with higher soil density and reduced total pore space. The porosity value was also consistent with the soil bulk density. Soil with high total pore space had a low bulk density, and vice versa.

The decrease in specific gravity from location 0 MAP to location 3 MAP was 4.88%, from location 3 MAP to location 5 MAP was 4%, and from location 5 MAP to location 9 MAP was 9%. While the soil dispersion index at location 0 MAP was included in the unstable category, at locations 3 and 5 MAP was included in the relatively stable category, and at location 9 MAP was included in the stable category.

The increase in the dispersion index value from location 0 MAP to location 3 MAP was 79.8%, from location 3 MAP to 5 MAP was 9.15%, and from location 5 MAP to 9 MAP was 19.63%. Higher soil specific gravity values and lower dispersion index at location 0 MAP compared to locations 3, 5, and 9 MAP (Figure 2) because the soil texture at these locations had a more dominant percentage of clay; the soil texture at location 0 MAP is sandy clay. In contrast, at location 9 MAP, it had a sandy clay loam texture. Soil texture significantly affects soil-specific gravity; soil with a high clay content has a higher specific gravity because clay particles are denser and have a greater amount of filled air space than sandy soil. High clay content in pineapple plants at 0 MAP age made the soil easily dispersed and unstable. When wet, the clay content in the soil will disperse into mud, and when dry, it will quickly harden into a solid. In this process, the dispersed soil will clog pores, increasing bulk density and decreasing soil infiltration (Syaifuddin and Buhaerah, 2010). Ground penetration and soil compaction can be observed from soil bulk density, pore space, and penetration. Figure 3 shows the soil penetration resistance value at each location of the pineapple plant age.

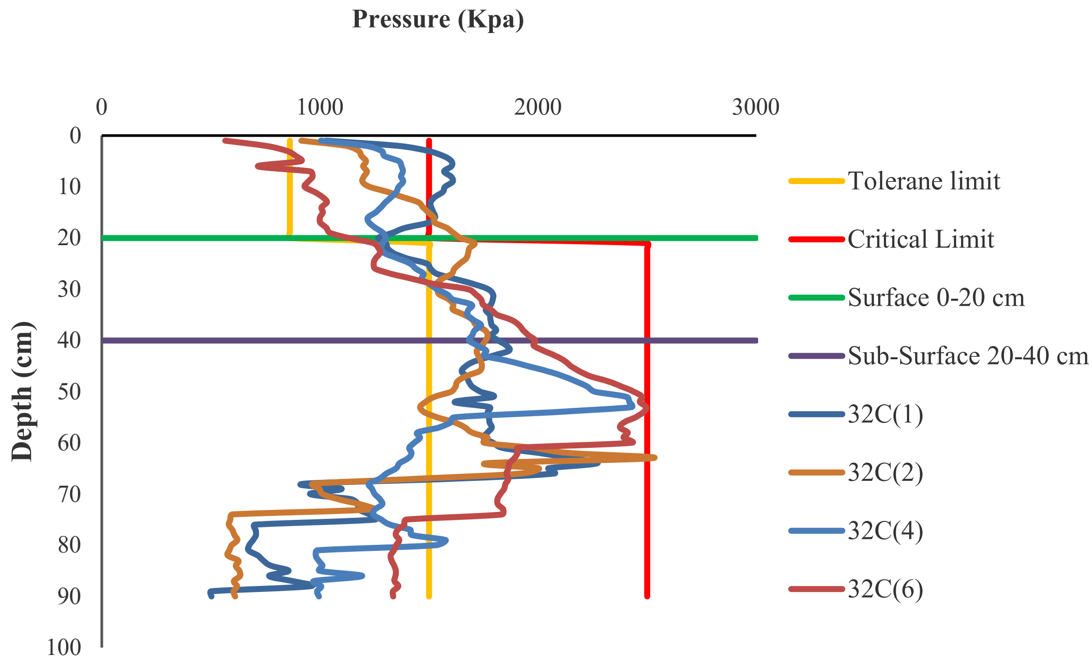

Figure 3A. Soil penetration resistance value at each location of the pineapple plant at the age of 0 MAP.

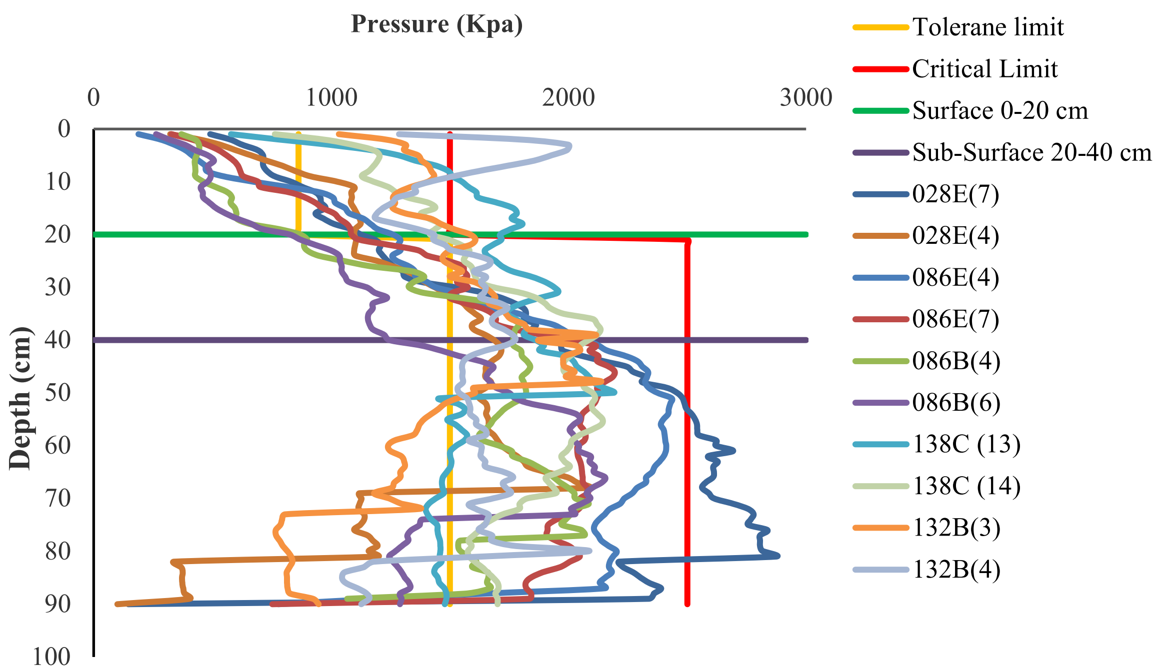

Figure 3B. Soil penetration resistance value at each location of the pineapple plant at the age of 3 MAP.

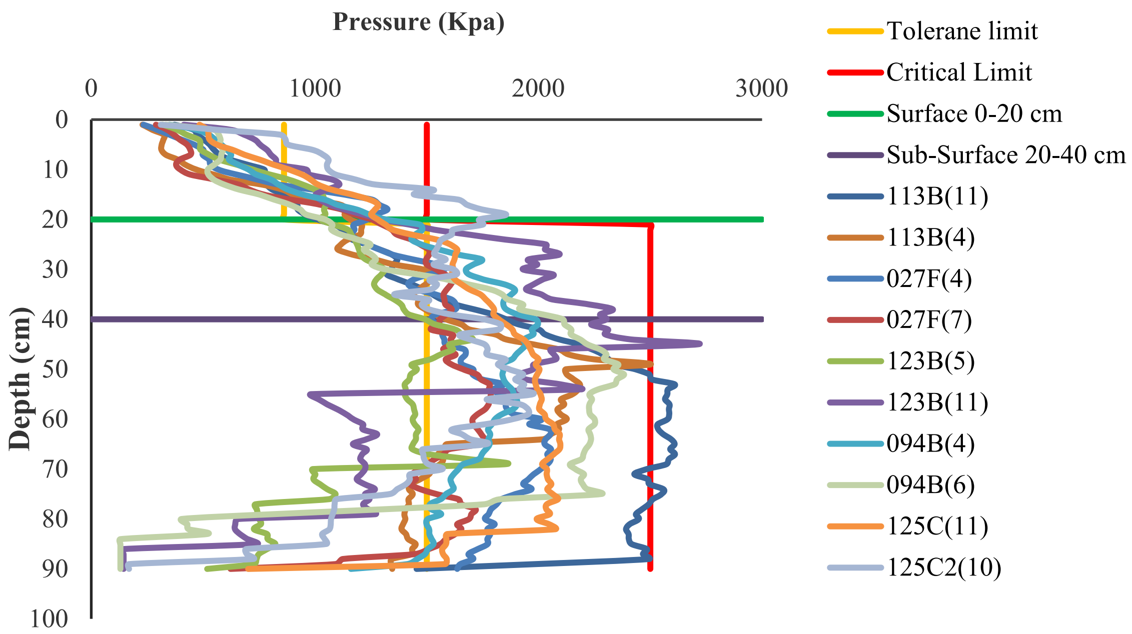

Figure 3C. Soil penetration resistance value at each location of the pineapple plant at the age of 5 MAP.

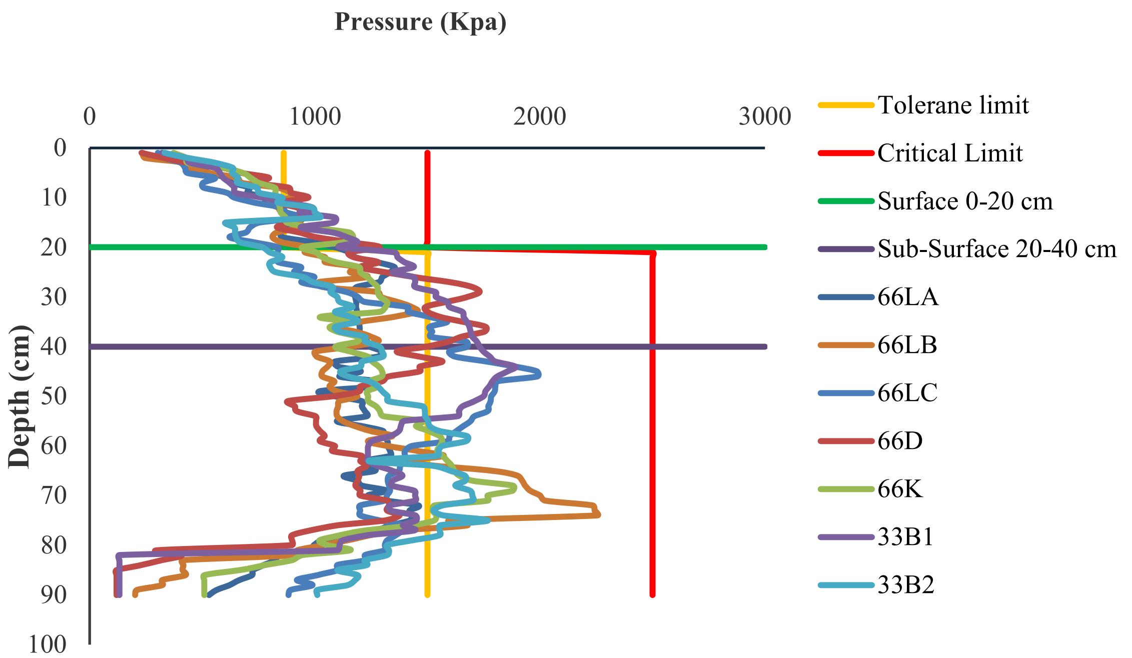

Figure 3D. Soil penetration resistance value at each location of the pineapple plant at the age of 9 MAP.

At the pineapple plant location, age 0 MAP, all locations have exceeded the soil penetration tolerance limit at the surface and in the sub-surface. At location 3 MAP, on the surface, 3 locations have exceeded the tolerance limit at 0-20 cm, and in the sub-surface, 3 locations have exceeded the tolerance limit at 20-40 cm. At location 5 MAP, on the surface, all locations began to pass the tolerance limit at a depth of 10-20 cm, and on the sub-surface, 3 locations have passed the tolerance limit at a depth of 20-40 cm, and 4 locations have passed the tolerance limit at a depth of 35-40 cm. At location 9 MAP on the surface, 4 locations passed the tolerance limit at 18-20 cm, namely 66LB, 66LA, and 33B1. Moreover, 66LD and 2 locations exceeded the tolerance limit in the sub-surface section, namely locations 33B1 and 66LD at a depth of 25 cm. In addition, several locations showed that the deeper the soil penetration value, the greater the soil compaction. The provision of compost effectively reduced the level of soil penetration on the surface. There were differences in soil penetration resistance values before compost application, which was 0 MAP higher than in soil applied with compost fertilizer at 3, 5, and 9 MAP. In addition, compost provision was optimal at 9 MAP for pineapple plants. The effect of applying cow dung compost on soil physical properties can be optimal after 9 months of application. This is due to compost's slow-release nature: its nutrients are released continuously over an extended period (Novitasari and Caroline, 2021). The lower penetration rate at nine months was due to the compost applied to the soil being more fully decomposed by then. The length of the compost decomposition process is due to the very high lignin content in cow dung, bamboo, and bromelain. Lignin is defined as an amorphous polymer whose chemical structure is very different from cellulose and hemicellulose; cow dung has 20.2% lignin, which is a component that is difficult to decompose; bamboo has a lignin content ranging from 21.98% to 33.43% (Nawawi et al., 2019).

The relationship between soil bulk density, total pore space, dispersion index, specific gravity, and soil organic C with soil penetration

A correlation test was conducted for each variable to determine relationships among soil bulk density, total pore space, index dispersion, specific gravity, soil organic C, and soil penetration. The correlation test (Table 4) showed that soil compaction and penetration were significantly correlated with soil bulk density, total pore space, soil dispersion index, and soil-specific gravity ($p<0.05$). There was a positive correlation ($p<0.05$) between bulk density and other variables except for total pore space and dispersion index, which were negatively correlated, at the pineapple plantation age of 5 and 9 MAP; so the higher the soil bulk density, the higher the soil specific gravity and penetration, the lower the pore space and dispersion index. In soil penetration, there was a positive correlation ($p<0.05$) between soil penetration and bulk density and specific gravity, and there was a negative correlation ($p<0.05$) between penetration and pore space and dispersion index at the pineapple plantation ages of 5 and 9 MAP. So, the higher the penetration, the higher the soil-specific gravity and bulk density, and the lower the pore space and dispersion index. The correlation observed at location 9 is due to the pineapple plant's age affecting the soil's physical properties relevant to its roots. Older plants tend to have a more complex and developed root system, which can increase biological activity in the soil and expand the soil pore space, reducing penetration and soil bulk density. Bulk density is a physical property that can describe the level of soil density in volume units. Soil with high organic matter content will have a low bulk density because organic matter influences soil aggregation, thereby affecting total porosity (Shaheb et al., 2021).

Table 4. Correlation for each observation variable.

Location Age	Variable	Correlation Coefficient (r)					
		1	2	3	4	5	6
0 MAP	Bulk density	1.0					
	Total pore space	-0.90	1.0				
	Dispersion index	0.65	0.54	1.0			
	Particle density	0.71	-0.18	-0.069	1.0		
	Aggregate	0.16	0.17	0.15	-1.15	1.0	
	Penetration	0.9*	-0.94	-0.90	0.62	0.51	1.0
3 MAP	Bulk density	1.0					
	Total pore space	-0.64	1.0				
	Dispersion index	0.27	0.56	1.0			
	Particle density	-0.55	-0.30	0.34	1.0		
	Aggregate	0.31	0.60	0.45	-0.14	1.0	
	Penetration	-0.42	0.54	0.52	0.18	-0.77*	1.0
5 MAP	Bulk density	0.1					
	Total pore space	-0.71*	1.0				
	Dispersion index	-0.72*	0.55	1.0			
	Specific gravity	0.61*	-0.49	-0.40	1.0		
	Aggregate	0.43	-0.61	0.03	-0.57	1.0	
	Penetration	0.93*	-0.73*	0.70*	0.75*	-0.61	1.0
9 MAP	Bulk density	1.0					
	Total pore space	-0.77*	1.0				
	Dispersion index	-0.87*	-0.80*	1.0			
	Particle density	0.87*	0.78*	-0.88*	1.0		
	Aggregate	0.02	-0.4	0.16	-0.19	1.0	
	Penetration	0.95*	-0.80*	0.91*	0.86*	0.02	1.0

Aggregates in the soil affect the formation of soil pores because the soil pore space adheres to the soil aggregate. Low aggregate stability will cause the soil structure to be easily destroyed by the impact of raindrops and the load on the top layer of the soil (Refliaty and Marpaung, 2010). The destruction of soil structure will block soil pores with aggregate particles, allowing the soil to compact and erode more quickly (Ahmad et al., 2016).

Conclusion

The research findings indicated that applying compost at a rate of 50 t ha^{-1} effectively reduced soil compaction and strength. Compost application could still improve soil aggregates and soil dispersion index up to 9 months after planting because organic materials bind soil particles together, making the soil more friable, as evidenced by the decrease in bulk density. Lower bulk density values correspond to higher total soil pore space, reducing soil compaction. The reduction in compaction reflects a decrease in soil strength.

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