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Comparison on soil properties of upper and lower part of potted strawberry

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Abstract

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Cultivation of strawberry (*Fragaria x ananassa* Duch.) in potted soil depends on the depth of pots and fertility of the substrate. The objective of study was to compare the physical and chemical soil properties of potted strawberries with that of field soil (Inceptisol), and the soil properties between the upper and lower layers of different ages and cultivars of potted strawberries. The soil samples were taken from 50-cm potted strawberries including two-year-old Sagahonoka and Earlibrite strawberries, and six-month and one-month-old Mencir strawberries. The mean values of chemical and physical properties in both layers were compared using t-test a ($p < 0.05$). The soil organic-C of all potted strawberries was similar to field soil but total-N, potential-K, C/N, and cation exchange capacity were higher than field soil. The soil in upper and lower parts contained medium organic-C, high total-N, low C/N, high potential P and K, CEC, and BS; but low in available-P. The upper layer of the potted soil of all strawberry cultivars and ages had higher available-P, potential-P, potential-K, and exchangeable K^+ and Mg^{2+} than the lower layer. However, the pH, organic-C, total-N, CEC, BS, Ca^{2+}, Na^+, H^+, and Al^{3+} in both layers were not different. Six-month- and one-month-old potted soil had higher C/N and available P than two-year-old potted soil. Generally, the bulk density, total porosity, and water content of both part of potted is similar. Higher bulk density and lower porosity were shown by six-month-old potted Mencir strawberries. Application of animal manure is suggested to increase SOC, C/N, and available P.

Keywords: Chemical properties; Field; Soil Nutrient; Physical properties

Introduction

The strawberry (*Fragaria x ananassa* Duch.) is a berry plant native to subtropical countries (Guerrero-Chavez et al., 2015). In tropical regions, strawberries are cultivated at higher altitudes since plants need lower temperatures for the fruit set and ripening (Masaru et al., 2016; Hong & Eum, 2020).

Nowadays, some strawberry production is carried out in the raised bed system using soilless substrate composed of agricultural wastes and minerals (Palencia et al., 2016; Hindersah et al., 2021; Kaushalya Madhavi et al., 2021) coir fibre, perlite and rock wool. Worldwide, most cultivation areas are in open fields, such as in America, India, China, United Kingdom and Indonesia. Soil provides nutrients and water, and supports the root system of strawberry (Ors & Anapali, 2010), but induce soil-borne diseases infestation (Meszka & Michalecka, 2016). Nonetheless, in the area where the soilless-media components included coco fiber, peat moss, rice husk and perlite are not affordable, field soil is important for potted-strawberries cultivation.

In Indonesia, the open field strawberries usually are performed in 50-cm high pots composed of field soil and organic matter (OM) mainly animal manure. The organic matter is necessary to enhance yield in soil-based strawberry production (Hoehne et al., 2020; Ilari et al., 2021; Sayğı, 2022) respectively. Soil quality indicator improvement after OM amendment is including increase in organic carbon, essential nutrients, cation exchange capacity, and water content (Murphy, 2015). Even though chemical fertilizer was regularly added for continuous nutrient supply, fruit yield of this cultivation practice was low and plant performance was not optimum. Low productivity might be caused by the reduced soil fertility in potted-soil and the soil compaction in the lower layer after growing strawberry for years in such potting soil.

Intensive application of chemical fertilizers might decrease the soil organic matter (SOM) and induce soil compaction (Pahalvi et al., 2021). Nitrogen fertilizer enhances soil organic mineralization and reduces SOM; under severe soil compaction, nitrate absorption is reduced, N assimilation is disrupted, and N metabolism is significantly limited (Wang et al., 2013).

Strawberry has a shallow root system; in the open field, the root length is approximately 21.5 cm (Mattner et al., 2018). The 7-cm high bed produce higher strawberry yield than 15-cm one (Natsheh et al., 2015). Sharma et al. (2022) explained that the root growth of strawberries grown in 35- and 37-cm deep pots was reduced compared to 25-cm deep pots.

The soil compaction in the lower layer of potted strawberries might be related to high bulk density (Db) that causes slow water percolation, excess water in the soil, and low crop growth and yield (Pan et al., 2021; Liu et al., 2022). Limited water percolation induces oxygen deficiency, limits the growth of coleoptile and root, and increases root death (Shaheb et al., 2021; Walne & Reddy, 2021).

Although potted soil is commonly used for strawberry cultivation in Indonesia, the study on potted strawberry soil quality after a certain duration of strawberry cultivation is limited. The study aimed to compare the chemical and physical soil properties of potted strawberries with that of natural soil, and their differences between the upper- and lower-layer soil of the different varieties of potted strawberries at different planting duration.

Materials and Methods

Experimental Site

The study was conducted in the strawberry plantation at Pacet District, Cianjur, West Java, Indonesia (Figure 1) located at 959 m above sea level at 6°42′24″ S and 107°02′48″ E. Soil sampling and analysis were performed in September-December 2022.

Soil Collection

Four strawberry plants were already grown in 50 cm high polybags with 30 cm in diameter (Figure 2). The substrate was Inceptisols field soil, manure, and paddy husk (1:1:2; v/v). The field soil acidity was 7.99 (slightly alkaline) with organic-C 3.25%, total-N 0.38%, C/N 8.55, available P_2O_5 (P_{av}) 5.76 mg kg^{-1}, potential P_2O_5 (P_{pot}) 63.63 mg kg^{-1}, potential K_2O (K_{pot}) 113.14 mg kg^{-1}, cation exchange capacity (CEC) 23.67 cmol kg^{-1}, and base saturation 99.28%. The exchangeable K^+, Ca^{2+}, Mg^2, and Na^+ were 2.71, 31.44, 4.50, and 0.34 cmol kg^{-1} respectively. The Db was 1.112 Mg m^{-3}, total porosity 58.03%, and water content (WC) 25.76%. The soil texture was sandy clay loam.

Plants were fertilized with liquid fertilizers consisting of NPK compound fertilizers and animal waste. The liquid Fertilizer was applied by fertigation method of 50 ml per plant each week. Three cultivars of strawberries at three different planting period were cultivated at sampling time. The samples were taken from the following potted strawberries:

C1: Two-year-old Sagahonoka strawberry
C2: Two-year-old Earlibrite strawberry
C3: Six-month-old Mencir strawberry
C4: One-month-old Mencir strawberry

The soil samples were collected from the upper layer of potted strawberry (0–15 cm) and the lower layer, 15–50 cm (Figure 2).

Plots of each strawberry cultivation are composed of 12 rows with 15 pots each (Figure 2). The subsample number was six pots that were randomly chosen. A total of 500 g of disturbed soil was collected from each pot sample and mixed thoroughly before laboratory analysis. Undisturbed soil was collected by ring samplers from other pots at similar depths.

Soil Properties Determination

The following soil chemical properties were analyzed: the acidity (pH) was measured with a pH meter, the organic-C was determined with the Walkley-Black method, the total-N was determined by a modified Kjeldahl method, the P_{av} was analyzed by using a spectrophotometer after Olsen extraction, while the P_{pot} and K_{pot} were extracted by HCl and determined on a flame photometer. The CEC measurement was performed by CH_2COONH_4 extraction; exchangeable K, Mg, Na, and Ca were determined by flame photometer after soaking the samples in a neutral CH_2COONH_4 solution for 24 h. Base Saturation and C/N ratio were calculated. Chemical analysis followed the Association of Analytical Chemistry proximate analysis (Latimer Jr, 2016).

Fig. 1. The location of the study area in West Java Province

a) b)

Fig. 2. Potting strawberries in Pacet District (a) and the soil layers of two-year-old soil (b)

Physical properties analysis followed by the International Soil Reference and Information Centre (ISRIC, 2002). The Db was measured by gravimetric method and then by calculation of dry weight to soil volume ratio. Total porosity was calculated based on Db and particle density with a constant of 2.63 Mg m^{-3}. Water content was determined by gravimetric method after soil heating at 105°C for 24 h.

Statistical Analysis

Mean values and standard deviation of soil properties were calculated from two samples. Each soil characteristic of the upper and lower layers was compared by using the independent Student's t-test ($p < 0.05$) by using IBM SPSS Statistics software (version 29.0).

Results and Discussion

Soil Chemical Properties

Table 1 shows that soil organic-C (SOC) was ranging from 3.27-3.59% in the upper layer and 2.79-3.61% in the lower layer. The mean of SOC was 3.39% equal to 5.8% of SOM. The mean of total-N in the upper and lower layers of soil was 0.42–0.64% and 0.33 – 0.44% respectively. The upper layer has a C/N of 7.03 while the lower layer was 8.77. The average available P in the upper layer was 7.25 mg kg^{-1} while in the lower layer was 3.32 mg kg^{-1}. Upper and lower layers of soil contained P_{pot} 76.5 and 54.7 mg kg^{-1} respectively. The average K_{pot} of lower and upper layer was 183.7 and 135.7 mg kg^{-1}.

The C1 and C2 are two-year old but grown with different strawberry cultivar. All parameters in upper layer of C1 with Sagahanoka cultivar was higher than C2 (with Earlibrite cv) but the potential-K of C1 was higher than C2. The C3 and C4 are both grown by Mencir cultivar with different age. The organic-C in upper layer of C3 and C4 was relatively higher compared to C1 and C2; lower organic-C in lower layer of C3 and C4 was evidence compared to C1.

The exchangeable base and acidic cations were varied (Table 2). The K^+ was ranged from 4 – 5.18 cmol kg^{-1} in upper layer and 2.1 – 4.77 cmol kg^{-1} in lower layer; the mean of K^+ of each soil layer was 4.46 and 3.41 cmol kg^{-1}. The range of Ca^{2+} in upper and lower layer of soil was 20.1 – 35.04 and 13.11-28.03 cmol kg^{-1} respectively; the average value of each layer was 25.45 and 20.51 cmol kg^{-1}. The mean of Mg^{2+} and Na^+ in upper layer of soil were 7.64 and 0.43 cmol kg^{-1} respectively; while those of the lower layer was 4.28 and 0.58 cmol kg^{-1} subsequently. Table 2 shows that the upper and lower layers of soil had Al^{3+} ranging from 0–0.24 and 0–0.11 cmol kg^{-1} subsequently; while their H^+ in each layer was 0.01–0.34 and 0.17 – 0.52 cmol kg^{-1}. The K^+ and Ca^{2+} were lower than that of natural soil, but Mg^{2+} in the upper layer and Na^+ of both layers were higher than natural soil.

The CEC and BS of natural soil were 23.67 cmol kg^{-1} and 99.28%; an increase in CEC was recorded clearly in potted strawberries but the BS remained unchanged (Table 2). The mean CEC in the upper layer of soil was 35.17 cmol kg^{-1} and in the lower layer was 29.68 cmol kg^{-1}. The mean BS of the upper and lower layer was 99.19% and 98.57% subsequently. The results showed that the CEC and BS of each soil condition were high.

All potted strawberries had slightly lower pH than natural soil (7.99); the pH of soil samples was ranged from 7.11-7.79 (Figure 3). The pH was neutral to slightly alkaline because of high exchangeable cation (mostly K, Ca, Mg) and base saturation (Table 2). The Al^{3+} and H^+ were also low, which caused the alkalinity. The C4 in the lower layer had the highest K^+ (4.77 cmol kg^{-1}) and C2 on the upper layer had the highest exchangeable Al value (0.24 cmol kg^{-1}).

Table 1. Nutrient profile of upper and lower layer of potted-soil for strawberry cultivation

Potted-soil	Organic-C, %		Total-N, %		C/N		Available-P, mg kg^{-1}		Potential-P, mg kg^{-1}		Potential-K, mg kg^{-1}	
	U	L	U	L	U	L	U	L	U	L	U	L
C1	3.45 ± 0.06	3.61 ± 0.08	0.64 ± 0.14	0.44 ± 0.0	5.54 ± 1.31	8.20 ± 0.19	7.37 ± 0.39	2.64 ± 0.14	89.66 ±1.75	53.94 ± 1.14	160.26 ± 4.04	131.91 ± 6.19
C2	3.27 ± 0.6	2.76 ± 0.28	0.50 ± 0.04	0.38 ± 0.01	6.63 ± 0.59	7.35 ± 0.87	4.6 ± 1,43	2.19 ± 0.17	66.13 ± 2.62	47.55 ± 0.11	177.57 ± 5.5	81.65 ± 7.10
C3	3.74 ± 0.09	3.29 ± 0.43	0.42 ± 0.02	0.33 ± 0.01	9.03 ± 0.70	9.99 ± 1.73	7.07 ± 0.77	3.68 ± 0.86	67.94 ± 0.39	43.49 ± 3.56	180.75 ± 2.9	141.49 ± 4.98
C4	3.59 ± 0.35	3.45 ± 0.49	0.52 ± 0.01	0.35 ± 0.01	6.95 ± 0.59	9.54 ± 1.01	9.96 ± 0.30	4.80 ± 0.19	82.41 ±9.19	73.82 ± 23.0	216.30 ± 2.46	187.96 ± 2.68

Mean ± standard deviation (n = 2), U: Upper, L: Lower, C1: Two-year-old potted Sagahonoka, C2: Two-year-old potted Earlibrite strawberry, C3 = Six-month-old potted Mencir strawberry, C4: One-month-old potted Mencir strawberry

Table 2. Exchangeable ions, cation exchange capacity and base saturation of upper and lower layer of potted-soil for strawberry cultivation

Potted-soil	K^+, cmol kg^{-1}		Ca^{2+}, cmol kg^{-1}		Mg^{2+}, cmol kg^{-1}		Na^+, cmol kg^{-1}		Al^{3+}, cmol kg^{-1}		H^+, cmol kg^{-1}		CEC, cmol kg^{-1}		BS, %	
	U	L	U	L	U	L	U	L	U	L	U	L	U	L	U	L
C1	4 ± 1.40	3.31 ± 0.48	35.04 ± 2.89	20.69 ± 7.25	10.27 ± 1.41	5.16 ± 0.86	0.49 ± 0.07	0.53 ± 0.08	0.06 ± 0.07	0.00 ± 0.00	0.18 ± 0.00	0.52 ± 0.32	41.22 ± 4.84	29.76 ± 0.15	99.52 ± 0.18	98.08 ± 1.59
C2	4.59 ± 0.15	2.1 ± 0.13	20.01 ± 2.88	28.03 ± 3.42	5.52 ± 0.69	4.05 ± 0.42	0.49 ± 0.09	0.61 ± 0.24	0.24 ± 0.00	0.00 ± 0.00	0.01 ± 0.04	0.29 ± 0.16	36.82 ± 3.71	30.17 ± 1.97	98.90 ± 0.02	99.15 ± 0.52
C3	4.08 ± 0.16	3.49 ± 0.06	20.64 ± 3.56	13.11 ± 1.36	6.44 ± 0.72	3.53 ± 0.12	0.37 ± 0.01	0.44 ± 0.03	0.08 ± 0.04	0.11 ± 0.16	0.15 ± 0.12	0.34 ± 0.08	28.37 ± 3.59	27.04 ± 2.65	99.27 ± 0.34	97.82 ± 1.27
C4	5.18 ± 0.32	4.77 ± 0.28	26.11 ± 8.00	20.22 ± 3.17	8.36 ± 2.57	4.4 ± 0.48	0.38 ± 0.03	0.76 ± 0.02	0.00 ± 0.00	0.05 ± 0.08	0.34 ± 0.07	0.17 ± 0.00	34.27 ± 2.85	31.78 ± 4.60	99.10 ± 0.42	99.24 ± 0.35

Mean ± standard deviation (n = 2), U: Upper, L: Lower C1 = Two-year-old potted Sagahonoka strawberry, C2 Two-year-old potted Earlibrite, C3 = Six-month-old potted Mencir strawberry, C4 = One-month-old potted Mencir strawberry

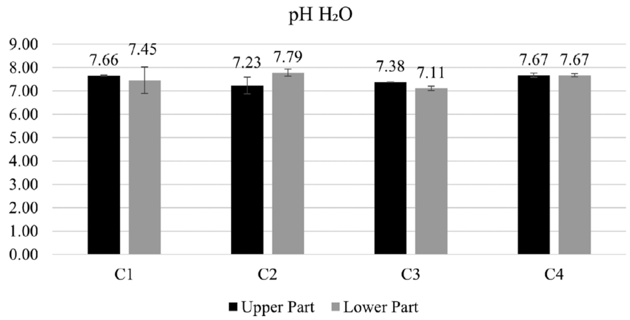

Fig. 3. Mean and standard deviation of pH of the upper and lower layer of various soil conditions

Based on the t-test, the upper layer of C1 has higher P_{av}, P_{pot}, K_{pot}, and Mg^{2+} (Table 3). Meanwhile, upper layer of C2 has higher K_{pot} and K^+. The P_{pot}, K_{pot}, and Mg^{2+} of the upper layer of C3 were significantly higher than the lower layer. However, the upper layer of C4 contained higher total-N and Na^+.

Soil Physical Properties

The mean Db, porosity, and WC of the upper layer of soil were 0.87 Mg m^{-3}, 67.55%, and 46.3%; while in the lower layer were 1.01 Mg m^{-3}, 61.85%, and 39.3% respectively (Table 4). There were no distinctive differences in soil physical properties between soil conditions. All samples have low Db; and high total porosity and WC.

Based on the t-test, the upper layer of potted soil of all soil conditions had similar WC compared with the lower layer. The Db and total porosity of all layers of C1, C2, and C4 were similar but the upper layer of C3 has significantly higher Db and total porosity (Table 5).

Based on the Indonesian soil fertility classification and Soil Test Interpretation Guide (Horneck et al., 2019), in general, the upper and lower layers of potted soil had medium SOC, high total-N, low C/N, and high P_{pot} and $_{Kpot}$; but low P_{av} and K^+. The SOC content of potted strawberries is not different with field soil although poultry manure and paddy husk were added. The potted strawberries were grown in open fields with daily irrigation but high temperatures mainly in the afternoon resulted in the lack of water that hence limited the OM decomposition. The SOC is a measurable soil organic; that has an essential role in the physical, chemical, and biological function of soil.

On average, total-N, K_{pot}, C/N, and CEC of soil were higher compared to field soil. The soil has medium SOC content and high CEC; therefore, the soil will adsorb nutrient cations with a greater proportion of nutrients supplied by chemical fertilizers such as NH_4^+, Ca^{2+}, and Mg^{2+}. In such condition, soil has the capacity to supply cations to the soil solution for root uptake; and cations are not susceptible

Table 3. The p-values of soil chemical properties differences between upper and lower layer of potted strawberries

Potted-soil	The difference value between an upper and lower layer of potted soil													
	pH	SOC	N	C/N	P_{av}	P_{pot}	K_{pot}	K^+	Ca^{2+}	Mg^{2+}	Na^+	Al^{3+}	H^+	CEC	BS
C1	0.66	0.48	0.18	0.1	0.01*	0.02*	0.03*	0.58	0.12	0.05*	0.66	0.32	0.28	0.08	0.12
C2	0.18	0.21	0.05	0.55	0.22	0.07	0.01*	0.01*	0.13	0.13	0.58	0.08	0.24	0.15	1.00
C3	0.052	0.28	0.16	0.91	0.14	0.01*	0.01*	0.04*	0.11	0.03*	0.07	1.00	0.20	0.71	0.12
C4	1.00	0.43	0.01*	0.93	0.07	0.81	0.95	0.31	0.44	0.17	0.01*	0.32	0.08	0.58	0.44

*Significant at $p < 0.05$ based on t-test

Table 4. Physical properties of the upper and lower layer of potted strawberry

Potted-soil	Bulk Density, Mg m^{-3}		Total Porosity, %		Water Content, %	
	U	L	U	L	U	L
C1	0.98 ± 0.10	1.05 ± 0.06	62.99 ± 3.92	60.48 ± 2.34	48.99 ± 4.91	39.40 ± 1.09
C2	0.70 ± 0.09	0.89 ± 0.02	73.50 ± 3.27	66.26 ± 0.76	47.93 ± 1.84	44.59 ± 9.47
C3	0.88 ± 0.06	1.13 ± 0.04	66.63 ± 2.38	57.27 ± 1.41	41.19 ± 4.38	36.71 ± 9.02
C4	0.87 ± 0.05	0.97 ± 0.06	67.09 ± 1.75	63.39 ± 2.21	47.25 ± 6.48	36.66 ± 2.07

Mean ± standard deviation (n = 2), U = Upper, L = Lower, C1 = Two-year-old potted strawberry cv. Sagahonoka, C2 = Two-year-old potted strawberry cv. Earlibrite, C3 = Six-month-old potted strawberry cv. Mencir, C4 = One-month-old potted strawberry cv. Mencir

Table 5. The p values of soil physical properties difference between the upper and lower layers of potted strawberries

Potted-soil	The difference value between an upper and lower layer of soil		
	Bulk Density, Mg m^{-3}	Total Porosity, %	Water Content, %
C1	0.519	0.517	0.114
C2	0.092	0.093	0.672
C3	0.041*	0.041*	0.964
C4	0.184	0.205	0.158

to leaching loss. Negative charges of soil are derived from soil particles and OM; studies verified that SOM contributes to the CEC of topsoil and subsoil (Ramos et al., 2018; Solly et al., 2020) a factor that is correlated with the physical and chemical qualities of highly weathered soils. In this study, we investigated the effects of TOCS on the physicochemical attributes of a Latosol after 10 years of no-till management in Mato Grosso State, Brazil. RESULTS: TCOS was highly correlated (r = 0.92).

Higher CEC and water-stable aggregates in soil facilitate available N and P for plant uptake (Muktamar et al., 2020; Cheng et al., 2023)limiting our ability to explore the role of soil-available nutrients in soil geochemical cycling and ecosystem sustainability. Here, we combined the spatial distribution of soil-available nutrients and chemical and aggregate properties from six soil types (subalpine meadow soil, meadow soil, dark brown soil, brown soil, yellow-brown soil, and cinnamon soil. The soil pH in all samples ranged from 7.11–7.79 which is slightly lower than field soil (7.99). The pH of the soil was too high for strawberry cultivation since the pH range for strawberry optimal growth is 5.3–6.5 (Klodd et al., 2021). Alkaline soil will gradually decrease the P availability (Ara et al., 2018). Field and potted soil have high BS which correlated with a slightly alkaline soil reaction.

The soil contained a high total-N that doesn't indicate the available NH_4^+ and NO_3^-. Higher total-N in pots was caused by intensive chemical and inorganic fertilization which is related to the low C/N due to high total-N content. The Inceptisols field soil contained low P_{av} that reflected in low P_{av} in potted strawberries. The available P forms in soil are $H_2PO_4^-$ and HPO_4^{2-}, but anionic nutrients are possibly leached out easily in sandy soil of potted strawberries due low anion exchange capacity (AEC). The inherent soil texture was sandy clay loam without clay minerals of 2:1 that contribute to soil AEC. The P_{pot} and K_{pot} of both layers of soil were high; the increase of each major nutrient was likely due to overdoses of P and K fertilizer. Application of organic fertilizer with inorganic also contribute to soluble P and K.

Surprisingly, the upper and lower layer of soil of two-year-old potted strawberries has similar Db, total porosity, and WC indicating that there was no soil compaction during two-year strawberry cultivation. However, the Db of the lower layer of six-month-old potted soil was significantly higher than the upper layer. These results confirmed that statistically soil compaction did not occur in most of the potted strawberries. Irrespective of the t-test, the lower layer of all potted soil had higher Db, lower total porosity, and WC (Table 4), indicating that the gradual decrease of the soil physical properties of the lower layer occurred. Watering also affected partial movement of soil particles through water percolation which clog pore space and increase bulk density (Al-Shamari et al., 2020). Management of OM is needed to maintain soil physical quality since growth properties and strawberry flowering time is also determined by physical properties (Ameri et al., 2020).

In general, Db of all sample were less than 1.6, which is not restricted to plant growth in sandy soil. The soil texture of the field soil was sandy clay loam which is soil with the tendency to be hard setting and can induce poor water and air infiltration. The application of bulky OM to improve soil physics including preventing soil compaction and oxygen deprivation (Jesús & Roblero, 2020). This was because the soil size blocks contribute to increase porosity (Hassan et al., 2019). Moreover, OM application increases strawberry growth and yield (Roussos et al., 2022; Kilic et al., 2023). Therefore, OM amendment is key to ensuring the soil quality and yield of potted strawberries.

Conclusion

Soil in any age of potted strawberries had similar SOC and pH, but higher total-N, potential-K, C/N, and cation exchange capacity than field soil. In general, the upper and lower layers of potted soil had medium organic-C, high total-N, low C/N, high P_{pot} and K_{pot}, CEC, and BS; but they have low P_{av}. Both soil layers in all soil conditions have the same SOC, total-N, pH, C, CN, Al^{3+}, H_{+}, CEC, and BS. Higher Pav, P_{pot}, K_{pot}, and Mg^{2+} were recorded in the upper layer of C1 compared to the lower layer; while the upper layer of C2 had higher K_{pot} and K^{+} than the lower layer. The upper layer of C3 clearly showed higher P_{pot}, K_{pot}, and Mg^{2+} than its lower layer. However, the upper layer of C4 had a higher total-N and Na^{+}. In general, the chemical properties of potted soil were not greatly different from the field soil. Likewise, the difference in chemical properties between the two layers is not great for any age of potted-strawberry. The upper layer of soil of potted strawberries has the potency to have lower Db, higher porosity, and higher WC compared with the lower layer. The significant increase of Db and decrease of total porosity was only shown by the lower layer of C3.

The study suggested that application of higher dose of bulky OM such as manure is needed to increase SOC, C/N, and P_{av}. Growing the strawberry in high pot should be considered as raised bed for easier maintenance instead of as effective growing media.

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