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Managing Coffee Fruit Husk as Compost to Improve Soil Fertility and Yield of Radish (*Raphanus sativus* L.)

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Abstract Coffee fruit husk, one of the residues in coffee agroforestry systems, is potentially managed into organic fertilizer to improve soil fertility and plant production. The study aimed to assess the compost quality from coffee fruit husk (i.e., fine and granular) and its impact on soil fertility and the production of radish. The research was conducted in 3 steps, including 1) compost preparation, 2) incubation research, and 3) field experiment for the application of coffee fruit husk compost on radish cultivation, starting from May 2018 to September 2019. The incubation and field research were designed with 9 treatments and 3 replications, including control, fine and granular compost of coffee fruit husk forms with four different application doses for each form. The result showed that granular compost was slowly decomposed, and consequently, the nutrient released was longer than fine compost. This was proven by the soil pH, soil organic C and soil exchangeable K were 5% to 63% lower in the application of granular compost than in the application of fine compost during 8 weeks incubation. Furthermore, in the field research, the application of 2.7 kg granular compost/plot (~ 9 tons/ha) increased 91% and 65% to 84% of radish production as compared to control and application of all doses of fine compost at 12 weeks after application.

Keywords Coffee Agroforestry, Coffee Fruit Husk Compost, Fine Compost, Granular Compost, Soil Chemical Properties

1. Introduction

The increase demand of food is accompanied by the extent of agricultural land, which is the result of conversion from forest or shrub land and / or intensive agriculture practices. Land-use change and intensive agriculture practices resulted in decreased nutrient concentration in the soil (such as C, N, Ca, Mg, Na) and soil nutrient stock, especially soil organic carbon and nitrogen [1]. As a consequence, the use of high inorganic fertilizers is a practical choice for farmers in supplying nutrients for plants and increasing plant production. This is due to the fact that inorganic fertilizers are easier to obtain, as well as fast nutrients released to the soil. However, the use of inorganic fertilizers has a negative impact on the environment, in particular air, water, and soil pollution. The previous study reported that fertilization increased nitrogen, organic carbon, and base cations in heavily weathered soils [2]. Furthermore, application of N fertilizers to the soil caused a residue of 2-10% in the surface water and ground water, increased soil acidity and decreased beneficial soil organism and soil organic matter, and also contributed to greenhouse gases emission [3, 4]. Therefore, organic fertilizer can be an alternative solution to minimize the excessive use of inorganic fertilizer in agricultural land and the negative effect of inorganic fertilizer for environment. The combination of inorganic and organic fertilizers in the form of compost or manure could increase exchangeable base cations in the soil resulting increases on soil fertility [5].

Compost is one of organic fertilizers that has high value for agronomically, economically and environmentally. The benefit of compost in agronomic performance, especially in radish cultivation, showed that the increases of application doses of commercial compost increased plant height, root diameter, and root fresh weight [6]. Economically, compost application is possible to increase benefit cost ratio in vegetable production through improving soil quality, increasing crop yield, and saving in inorganic fertilizer use such as urea, triple P, and KCl fertilizers [7]. Davis and Haglund [8] reported that saving on chemical fertilizer use results in decreased consumption of energy and consequently reduces carbon emission which is associated with inorganic nitrogen fertilizers manufacture. In addition, many previous researches showed the benefit of compost application in improving soil fertility (i.e., soil organic matter, total soil N, available P, and total porosity) and plant production such as broccoli, shallots, rice and tomatoes [9, 10, 11, 12]. However, beside kinds of raw materials and doses of compost, the effectiveness of compost on increasing soil nutrient content and plant production are determined by the form (i.e., powder, granule) of compost.

Compost is mainly produced and applied on agricultural land in the form of powder / fine due to fastly decompose and release nutrient. While, granular compost was chosen because it does not produce dust, prevents segregation, dissolves quickly in water, is easily absorbed by plants, and prevents excess doses of nutrients from rapid nutrient release [13, 14]. The other research showed that granular compost could delay the release of N by one month, thereby reducing the risk of N loss during the nursery period and increasing soil N supply during the rapid growth period in plants, as a consequence reducing N loss and minimizing environmental pollution [15].

Compost can be produced from harvesting residue (e.g., vegetable, food crop, cash-crop), manure, or organic waste. One of harvesting residues that can be used as compost material is coffee fruit husk from agroforestry systems in Universitas Brawijaya forest (UB Forest). Annually, the coffee production in UB Forest ranges from 200 - 600 kg ha^{-1} and totally is estimated approximately 60 - 180 tons in all UB Forest. If the coffee fruit husk reached 50-60% [16, 17], the total coffee fruit husk that might result from UB forest ranged from 31.5-94.5 tons. Unfortunately, the residue from the harvest is not well managed by the farmers and abandoned. Forest farmers in UB Forest prefer to apply chicken manure for the plants, purchased from chicken farms outside UB Forest area. As a consequence, the farmer's cost production is high and reduces the profit/income earned. Thus, the composting of potential waste might become a solution to answer a better sustainable land management for the UB forest farmers. Processing coffee husk waste into compost not only increases farmer's knowledge and skills in processing harvest waste into economically valuable products, but also develops zero waste management in UB Forest. This study was aimed to analyze the quality of compost from coffee fruit husk in UB forest and its impact on soil fertility and plant production.

2. Materials and Methods

2.1. Study Site

The study was conducted in the Universitas Brawijaya's education and trainee forest, and in the Laboratory of Soil Department, Faculty of Agriculture, Universitas Brawijaya, East Java – Indonesia. Universitas Brawijaya's education and trainee forest, better known as UB Forest, located at the slopes of Mount Arjuna between Batu City and Malang Regency (Karangploso and Singosari Districts), East Java - Indonesia. Geographically, the UB forest area is located in 7049'300" - 7051'363" S and 112034'378" - 112036'526" E coordinates. Around 70% (± 360 ha) area of UB forest was planted with coffee (i.e arabica, robusta, and local varieties) especially under pine and mahogany, and the rest area was covered by vegetable (cabbage, cauliflower, broccoli, carrots, taro, ginger and grass). Soil in UB forest is classified as Inceptisol and Andisol (USDA classification), soil particle dominated by silt, and characterized by moderate to high soil organic matter, low soil pH and soil available P, as well as low to moderate exchangeable base cations [18, 19].

2.2. Research Design

The research was conducted in three phases, starting from May 2018 until July 2019. In the first phase, we produced coffee fruit husk compost from May to October 2018. Then, incubation research for evaluation nutrient released from coffee fruit husk compost was conducted in the Soil Department – Universitas Brawijaya from May to October 2018 as the second stage of this research. Third, the field experiment in the UB Forest was conducted from

March to July 2019 to evaluate the effect of the application of coffee fruit husk compost on agronomic performance, in particular the yield of radish. Detailed activity from each phase will be explained below.

2.2.1. Producing Granule Compost from Coffee Fruit Husk

The study was started by preparation of raw materials, especially coffee fruit husk which was carried out in the UB forest after the farmer finish in coffee processing. To accelerate the composting or decomposition process, the raw material was grinded into smaller form with the machine. Prior to cut the compost material, the raw material of compost was air-dried to reduce the water content in the compost material because the wet raw material can disturb the grinding process or destroy the grinder knife. Hand squeeze method was used to feel the compost materials prior to the composting process. The optimum water content for aerobic composting is approximately 60% [20], or feels moist, but there was no water coming out when the compost material squeezed.

Table 1. The temperature during composting process of coffee fruit husk

Compost temperature (℃)							
Time measurement	Date	point of measurement					
		1	2	3	4	5	Average
1 (3-days)	7/5/2018	33	33	32	32	37	33.4
2 (7-days)	7/9/2018	42	42	45	44	46	43.8
3 (10-days)	7/12/2018	48	45	45	48	49	47
4 (14-days)	7/19/2018	43	42	42	43	42	42.4
5 (21-days)	7/26/2018	38	38	37	39	37	37.8
6 (28-days)	8/2/2018	35	35	36	35	34	35
7 (30-days)	8/4/2018	30	32	32	31	30	31

The composting process is carried out by following the standard operational procedure of composting at Ecogreen Recycling Plaza (ERP) Universitas Brawijaya. The process started by grinding of raw coffee fruit husk for size reduction. The small size of material will enlarge surface of the material to accelerate the composting / decomposition process. After that, powder compost material was sprayed evenly with Effective Microorganism-4 (EM4) and molasse (100 kg raw material of coffee fruit husk, added with 200 ml commercial microorganism of EM_4 and 400 ml molasse diluted by 20 L water). EM-4 consists of Lactobacillus sp (lactic acid bacteria), Saccharomyces sp (fermentation fungi), Rhodopseudomonas sp (photosynthetic bacteria), yeast, and Actinomycetes [21]. Then, the compost was covered with tarp to increase the temperature and to accelerate microbe activities. The temperature was checked every 3-4 days during 0 – 14 days composting and every week during 15 to 28 days composting (Table 1). If the temperature was above 50ºC, the compost material was reversed to maintain the humidity and temperature to accelerate the decomposition process. Besides that, compost was regularly reversed weekly at 14, 21, and 28 days of composting. In addition, inversing of compost material is important to remove excessive heat, and increase oxygen for the decomposer bacteria evenly, also to keep the humidity of compost material. The tarp was opened after 21 days of composting until harvesting to reduce the compost temperature and water content. Compost was harvested at 30 days, as shown by the physical appearance of the compost material was similar to soil color (the color was dark) and the temperature was close to room temperature (28 – 31 ºC; Table 1). Further, the mature compost was sieved with 4 mm mesh to get the fine compost. Last, the granule compost was produced from the fine compost using a granulator machine. The water content of compost before applied to the soil were 18.18% for fine compost and 14.11% for granule compost.

2.2.2. Evaluation of Nutrient Release from Coffee Fruit Husk Compost with Incubation Research

The Incubation research was conducted in a completely randomized design with 9 treatments and 3 replications. The research treatments included: 1) control (P0); 2) powder compost with a dose 2 tons/ha (P1), 3) powder compost with a dose 4 tons/ha (P2), 4) powder compost with a dose 8 tons/ha (P3), 5) powder compost with a dose 12 tons/ha (P4), 6) granule compost with a dose 2 tons/ha (P5), 7) granule compost with a dose 4 tons/ha (P6), 8) granule compost with a dose 6 tons/ha (P7), and 9) granule compost with a dose 12 tons/ha (P8).

The incubation research used two types of soil with different soil textures (such as Entisol and Inceptisol). The Entisol was collected from Wajak district, Malang Regency, Indonesia, with characteristic having high sand particle, soil bulk density 1.24 g cm^{-3}, and low nutrient content. While, the Inceptisol was taken from UB forest with characteristic having high silt content, crumb structure and soil bulk density 0.88 g cm^{-3}. The soil was collected from topsoil (0-20 cm), then air dried for 7 days and sieved 2 mm to separate from the plant roots.

At each soil type, soil has been grounded and sieved with a size of 2 mm, then 400 g air-dried soil was placed into plastic bag (total of 216 polybags from 9 treatments, 3 replications, dan 4-time observations). In the Inceptisol, the dose of compost per plastic bag included 0.36 g (~ 2 tons/ha), 0.72 g (~ 4 tons/ha), 1.44 g (~ 8 tons/ha), and 2.16 g (~ 12 tons/ha). While, application of compost in the Entisol consisted of 0.29 g (~ 2 tons/ha), 0.58 g (~ 4 tons/ha), 1.16 g (~ 8 tons/ha), and 1.74 g (~ 12 tons/ha). Before the compost mixed with soil, we measured water content of soil samples (e.g., air dried and field capacity). The soil water content for the air-dried soil was 11.3% for Entisol and 26.4% for Inceptisol. While, the soil water content at field capacity was 21.8% for Entisol and 40.8% for Inceptisol. Furthermore, compost from each treatment was mixed with soil, then deionized water was added until 100% field capacity (the amount of water was calculated based on the water content of field capacity, for example 77 ml for Entisol and 82 ml for Inceptisol). After the soil mixed with compost and water, the polybag was covered and incubated for 1, 2, 4, and 8 weeks. Variables measured include soil pH, soil organic C, total N, soil available P, and exchangeable base cations (K and Ca).

2.2.3. Field Experiment Application of Coffee Fruit Husk Compost on Radish Cultivation

The field experiment was conducted to evaluate the effectiveness of coffee fruit husk compost (both in the form of fine and granular) on radish cultivation (*Hortensis* L.). The treatments included: 1) control (0 kg/plot ~ 0 tons/ha; P1D0); 2) powder compost with a dose 0.9 kg/plot (~3 tons/ha; P1D1), 3) powder compost with a dose 1.8 kg/plot (~6 tons/ha; P1D2), 4) powder compost with a dose 2.7 kg/plot (~9 tons/ha; P1D3), 5) powder compost with a dose 3.6 kg/plot (~12 tons/ha; P1D4), 6) granule compost with a dose 0.9 kg/plot (~3 tons/ha; P2D1), 7) granule compost with a dose 1.8 kg/plot (~6 tons/ha; P2D2), 8) granule compost with a dose 2.7 kg/plot (~9 tons/ha; P2D3), and 9) granule compost with a dose 3.6 kg/plot (~12 tons/ha; P2D4).

The phases of the field experiment followed steps: 1) preparation of land (i.e., land clearing, soil tillage, preparing bed for each treatment, and compost application), 2) preparation of seed (seed sortation), 3) seed planting (direct seeding), 4) maintaining of plant growth (i.e., thinning and embroidery, weeding and hoarding, irrigation, and controlling pest and disease), 4) harvesting, and 5) plant observation. Preparation of land was started by clearing the soil surface from weed. Then, soil tillage was done using a hoe to improve soil physical properties and to make the bed (3.2 m x 1 m sized and distance among bed 50 cm), with the height of the beds between 35 cm and 40 cm. After that, compost was applied according to the treatment. The compost was spread in the soil surface.

Prior to planting, seed sortation was conducted to choose the good quality of radish seed. The radish crop was planted by direct seeding with a spacing of 20 cm x 20 cm, which is the ideal spacing for radishes. The total crop population was 80 plants per bed. Plant maintenance is carried out by thinning and embroidery on 14 days after planting, leaving one plant per planting hole. Then, controlling of weed, pest, and disease was conducted to maintain crops growing optimally and minimize the pest and disease attack. Meanwhile, irrigation was carried out using a rainfed system. Radish harvesting was done at the age of 98 days or 3-4 months after planting.

Plant observations were carried out by collecting data on plant production including root length, root diameter, fresh weight of root per plant, root production per square meter, and root yield per plot. The study also estimated total root yield per hectare (ton/ha) by multiplying the yield per plant (kg) with the percentage of land effectiveness in a hectare (10000 m^2) divided by the harvest plot area (3.2 m^2). While, the percentage of land effectiveness in this study was 47%, calculated from total beds area (3.2 m^2 x 27 beds) divided by total plot area (37 m x 5 m), then multiplied by 100%.

Further, the study calculated agronomic efficiency as a short-term indicator of the impact of application coffee fruit husk compost in radish cultivation. Agronomic efficiency was calculated by following the equation of López-Bellido and López-Bellido [22] and Bhunia et al. [23]. In math, agronomic efficiency was calculated from yield in fertilizer treatment minus yield in control or without fertilizer application, then divided by the amount of fertilizer applied.

2.3. Laboratory Analysis

Laboratory analysis was conducted for measuring the quality of compost fruit husk (such as pH, total N, P, K, and C) and soil nutrient from incubation research (i.e., soil pH, soil organic C, total N, soil available P, and exchangeable K and Ca). Prior to laboratory analysis, the coffee fruit husk compost and soil were air-dried and sieved in 2-mm mesh. For compost and soil samples, total organic C and total N were measured by using Walkey and Black method [24] and Kjeldahl method [25], while total P (in the compost) and available P (in the soil) were determined by spectrophotometry method (Indonesian Soil Research Institute [26]). In addition, soil exchangeable K and Ca were extracted using NH_4OAC buffer pH 7, then measured using flamephotometer and titrimetric methods. Further, soil pH was measured using glass electrode with H_2O for extraction. The nutrient in coffee fruit husk compost was measured before running the incubation research, whereas soil nutrient content was measured at 1, 2, 4, and 8 weeks after incubation.

2.4. Statistical Analysis

The research data consisted of laboratory data in the form of nutrient availability and data field on plant growth and yield. Prior to statistical analysis, all data was tested on the normality using the Shapiro-Wilk's test. To assess differences in soil pH and nutrient among different types and doses of coffee fruit husk compost during 1, 2, 4 and 8 weeks incubation was conducted using 5% ANOVA with a completely randomized design followed by Duncan test (5%). While the data obtained in the field were analyzed using ANOVA at the 5% level with randomized block design followed by the Duncan test (5%). All data were analyzed using R statistical program version 4.1.0.

3. Results and Discussion

3.1 The Quality of Coffee Fruit Husk Compost

The quality of coffee fruit husk compost (fine and granule) matches the compost quality standards 2004 according to National Standarization Agency or Badan Standarisasi Nasional (BSN), Indonesia (Table 2 columns B and C). Compared to the results that were measured by Soil Chemistry Laboratory Faculty of Agriculture, Tanjungpura University which was reported by Ramli, Zulfita, and Safwan [26], coffee fruit husk compost (fine and granule) of our study is higher in total organic-C and total P, but lower in total N and total K. In contrast, coffee fruit husk compost in our research had higher total N and K, but lower total C and P as compared to those in Yenani, Santoso, Sutanto, Muhfahroyin [28] who measured those nutrients after one month composting of coffee husk. The differences of our result with the previous research were probably due to that the raw materials might contain different nutrients concentrations (C, N, P, K) and different composting methods. This result showed that the quality of coffee fruit husk compost produced was able to compete with compost produced by other producers. Based on these comparisons, coffee fruit peel compost from this study is recommended to improve agricultural lands.

3.2. Analyzing Nutrient Release from Different Form (e.g., fine and granule) and Doses of Coffee Fruit Husk Compost Application in Inceptisol and Entisol within Incubation Research

Inceptisol in the UB Forest was formed from volcanic materials (i.e breccias, lava, tuff breccias, and tuffs) of Mount Arjuna-Welirang complex volcanoes [29]. Based on the laboratory measurement prior to incubation research and compared to the criteria of soil analysis by Indonesian Soil Research Institute [26], the Inceptisol had characteristics such as the soil pH was classified as slightly acid (pH 5.55), the total nitrogen and available P were low to very low (0.2 g N/100g soil and undetectable of available P), whereas the soil organic C (2.59 g/100g) and exchangeable base cations (3.63 me K/100g and 7.2 me Ca/100g) were categorized as medium to high. While the Entisol had the properties including soil pH that was slightly acid (pH 6.21), while soil organic C (1.96 g/100g), total N (0.14 g N/100g), and exchangeable base cations (0.26 me K/100g and 3.69 me Ca/100g) were low, and soil available P (8.77 mg P/kg) was medium. The low content of soil organic matter, total N, and exchangeable base cations indicated that the soil has been degraded, therefore it is necessary to apply organic fertilizer. The addition of organic fertilizer not only increased organic matter but also increased soil nutrients due to coffee fruit husk compost containing essential nutrient such as of N and K (1.91% and 0.36%). The low available P in Inceptisol within UB Forest probably due to the P is strongly bound by allophane mineral, which resulted from volcanic ash material of Mount Arjuna-Welirang complex volcanoes [29]. In other studies, Entisols and Inceptisol tend to have low exchangeable base cations [19,30,31].

Table 2. pH and nutrient content in Coffee fruit peel compost compared to the previous studies and organic fertilizer standard according to Indonesian Standardization Agency (BSN) 2004

Quality indicator	Fine coffee fruit husk compost	Granule coffee fruit husk compost	Coffee fruit husk compost[27]	Coffee fruit husk compost[28]	Compost quality standard based on Indonesian standardization agency[21]
A	B	C	D	E	F
pH H_2O	7.35 ±0.05	7.0	-	7.20	6.80 – 7.49
C- organic (%)	19.70 ±0.91	20.31	10.8	29.8	9.8 – 32
Total N (%)	1.91 ±0.15	1.90	4.73	0.70	Minimum 0.4
C/N	10.50 ±0.50	11	2.28		10 - 20
Total P (%)	0.35 ±0.02	0.29	0.21	0.59	Minimum 0.1 (P_2O_5)
Total K (%)	1.07 ±0.02	2.08	2.89	0.46	Minimum 0.20 (K_2O)

Table 3. Analysis of soil pH and nutrient content from different forms and doses of coffee fruit husk compost in Inceptisol - UB Forest during 8-weeks incubation research

Treatment	pH H_2O				Soil organic C (%)			
	1 WAI	2 WAI	4 WAI	8 WAI	1 WAI	2 WAI	4 WAI	8 WAI
P0	5.55±0.0	5.40±0.0	5.38±0.0 b	5.23±0.0	2.59±0.1	1.83±0.3 a	3.10±0.2	2.22±0.2
P1	5.54±0.0	5.41±0.0	5.36±0.0 b	5.33±0.0	2.58±0.0	2.29±0.0 b	2.86±0.1	2.67±0.1
P2	5.47±0.0	5.28±0.1	5.38±0.0 b	5.22±0.1	2.38±0.1	2.33±0.1 b	2.72±0.1	2.32±0.1
P3	5.54±0.0	5.39±0.0	5.43±0.0 b	5.22±0.0	2.63±0.1	2.58±0.0 b	2.55±0.1	2.68±0.0
P4	5.60±0.0	5.43±0.0	5.36±0.0 b	5.30±0.0	2.42±0.1	2.45±0.1 b	2.67±0.2	2.58±0.1
P5	5.40±0.1	5.22±0.1	5.25±0.0 a	5.22±0.0	2.56±0.2	2.19±0.1 ab	2.53±0.1	2.86±0.1
P6	5.53±0.1	5.42±0.1	5.22±0.0 a	5.27±0.0	2.46±0.1	1.80±0.4 a	2.43±0.3	2.52±0.1
P7	5.46±0.1	5.39±0.0	5.22±0.0 a	5.26±0.0	2.52±0.1	2.56±0.0 b	2.48±0.1	2.76±0.1
P8	5.59±0.0	5.41±0.0	5.27±0.0 a	5.26±0.1	2.39±0.2	2.65±0.1 b	2.60±0.0	2.73±0.2
Sig.	0.32	0.12	<.001	0.39	0.18	0.003	0.28	0.07
	Total N (%)				Available P (mg/kg)			
P0	0.20±0.00	0.21±0.0	0.21±0.0	0.21±0.0	0.00±0.0	5.71±1.3	12.29±1.1	4.31±0.8
P1	0.20±0.01	0.21±0.0	0.21±0.0	0.21±0.0	0.00±0.0	4.75±1.1	13.54±0.5	4.89±0.3
P2	0.20±0.00	0.21±0.0	0.22±0.0	0.21±0.0	0.00±0.0	4.72±1.0	12.22±2.0	7.54±2.5
P3	0.21±0.00	0.21±0.0	0.19±0.0	0.20±0.0	0.00±0.0	4.92±1.2	16.01±1.8	4.46±0.3
P4	0.21±0.00	0.22±0.0	0.20±0.0	0.21±0.0	0.00±0.0	7.96±1.2	17.21±2.8	4.83±0.6
P5	0.20±0.00	0.22±0.0	0.18±0.0	0.21±0.0	0.00±0.0	6.43±1.4	10.89±1.1	3.45±0.1
P6	0.27±0.07	0.21±0.0	0.19±0.0	0.20±0.0	0.00±0.0	6.24±1.0	10.53±1.1	3.95±0.3
P7	0.21±0.00	0.21±0.0	0.19±0.0	0.20±0.0	0.00±0.0	4.57±1.0	13.30±1.3	4.17±0.0
P8	0.21±0.00	0.21±0.0	0.19±0.0	0.19±0.0	0.00±0.0	10.15±1.4	12.22±0.3	4.79±0.6
Sig.	0.55	0.72	0.43	0.40	0	0.10	0.08	0.27
	Soil exchangeable K (me $100g^{-1}$)				Soil exchangeable Ca (me $100g^{-1}$)			
P0	3.63±0.1 a	4.02±0.3 ab	4.61±0.2 b	4.19±0.1	7.20±0.2 a	7.36±0.2 a	11.18±0.4 c	8.11±0.2 a
P1	3.76±0.2 a	4.30±0.0 abc	4.42±0.1 b	4.23±0.3	7.83±0.3 ab	7.89±0.7 ab	10.46±0.8 bc	9.38±0.2 b
P2	4.25±0.2 ab	3.83±0.1 a	4.08±0.1 ab	3.85±0.2	7.09±0.2 a	8.15±0.2 ab	10.67±0.6 bc	8.16±0.2 a
P3	4.65±0.1 b	4.65±0.2 bc	4.45±0.2 b	4.40±0.2	8.78±0.3 bc	8.12±0.6 ab	10.68±0.3 bc	8.17±0.3 a
P4	4.25±0.2 ab	4.15±0.3 abc	4.20±0.2 ab	4.25±0.2	8.83±0.7 bc	8.86±0.4 abc	9.00±0.5 ab	8.55±0.5 ab
P5	4.66±0.5 b	4.00±0.1 ab	3.67±0.1 a	4.41±0.1	9.28±0.2 c	9.03±0.4 abc	8.18±0.3 a	8.94±0.2 ab
P6	4.08±0.0 ab	4.24±0.2 abc	3.56±0.2 a	4.41±0.2	8.34±0.6 bc	9.18±0.1 bc	9.63±0.8 abc	8.62±0.2 ab
P7	4.52±0.4 b	4.82±0.3 c	3.63±0.3 a	4.39±0.3	8.70±0.8 bc	9.16±0.6 bc	7.93±0.2 a	8.30±0.3 a
P8	3.75±0.2 a	4.79±0.2 c	3.87±0.27 ab	4.52±0.1	7.23±0.1 a	10.41±0.7 c	9.00±0.7 ab	8.78±0.3 ab
Sig.	0.01	0.04	0.01	0.51	0.01	0.03	0.01	0.04

Note: P0 = Control (P0); P1 – P4 = Fine compost with dose 0.36 g (~2 tons ha^{-1}); 0.72 g (~4 tons ha^{-1}); 1.44 g (~8 tons ha^{-1}); 2.16 g (~12 tons ha^{-1}); P5 – P8 = Granule compost with dose 0.36 g (~2 tons ha^{-1}); 0.72 g (~4 tons ha^{-1}); 1.44 g (~8 tons ha^{-1}); 2.16 g (~12 tons ha^{-1}); Means ± s.e.d followed by different lowercase letters indicate significant differences among treatments (analysis of variance with Duncan test at $P \leq 0.05$); WAI = week after incubation.

Table 4. Analysis of soil pH and nutrient content from different forms and doses of coffee fruit husk compost in Entisol – Malang regency during 8-weeks incubation research

Treatment	pH H_2O				Soil organic C (%)			
	1 WAI	2 WAI	4 WAI	8 WAI	1 WAI	2 WAI	4 WAI	8 WAI
P0	6.21±0.1	5.68±0.0	5.84±0.0	5.61±0.2 a	1.96±0.0	1.94±0.1 c	2.01±0.1 b	1.83±0.1
P1	5.79±0.1	5.77±0.1	5.63±0.0	6.87±0.0 d	1.64±0.2	1.65±0.1 b	2.18±0.1 b	1.75±0.3
P2	6.22±0.3	5.66±0.0	6.07±0.4	6.91±0.1 d	1.38±0.0	1.61±0.1 b	2.13±0.1 b	1.88±0.1
P3	6.20±0.3	5.73±0.0	5.84±0.3	6.95±0.1 d	1.42±0.2	1.70±0.1 b	1.38±0.1 a	1.80±0.0
P4	5.93±0.2	6.09±0.3	6.08±0.4	7.00±0.0 d	1.81±0.2	1.35±0.1 ab	1.13±0.1 a	2.04±0.1
P5	5.92±0.2	5.80±0.2	5.88±0.1	6.33±0.0 b	1.70±0.0	1.35±0.2 ab	1.24±0.1 a	2.04±0.2
P6	5.91±0.0	6.00±0.2	5.85±0.2	6.70±0.1 c	1.47±0.1	1.10±0.3 a	1.02±0.2 a	1.82±0.2
P7	5.95±0.0	5.93±0.0	5.77±0.1	6.46±0.2 b	1.85±0.2	1.44±0.1 ab	1.29±0.2 a	2.15±0.1
P8	6.02±0.1	5.93±0.1	5.63±0.0	6.47±0.2 b	1.68±0.1	1.42±0.0 ab	1.37±0.2 a	1.74±0.2
Sig.	0.44	0.32	0.84	<.001	0.098	0.017	<.001	0.55
	Total N (%)				Available P (mg/kg)			
P0	0.14±0.0 b	0.15±0.0	0.15±0.0 ab	0.14±0.0 b	8.77±3.0 a	19.63±4.3 b	3.22±0.4 a	3.83±0.8 a
P1	0.12±0.0 a	0.13±0.0	0.14±0.0 a	0.11±0.0 a	11.31±2.6 a	11.69±1.0 ab	5.07±0.8 b	7.98±0.2 bc
P2	0.11±0.0 a	0.12±0.0	0.12±0.0 a	0.10±0.0 a	13.25±2.0 ab	10.72±1.5 a	5.75±0.7 b	7.58±0.8 bc
P3	0.11±0.0 a	0.13±0.0	0.17±0.0 b	0.11±0.0 ab	8.77±3.0 b	19.63±4.3 ab	8.05±3.4 b	8.39±0.8 bc
P4	0.12±0.0 a	0.12±0.0	0.12±0.0 a	0.11±0.0 a	16.71±2.9 ab	10.20±0.5 a	5.96±1.6 b	9.26±0.7 c
P5	0.12±0.0 a	0.10±0.0	0.13±0.0 a	0.13±0.0 ab	13.36±1.0 ab	16.27±2.9 ab	6.17±1.0 b	7.62±0.3 bc
P6	0.11±0.0 a	0.12±0.0	0.12±0.0 a	0.13±0.0 ab	15.27±2.7 ab	15.25±4.1 ab	6.00±0.0 b	5.80±0.5 b
P7	0.12±0.0 a	0.12±0.0	0.14±0.0 ab	0.13±0.0 ab	18.31±1.9 ab	15.85±1.8 ab	7.17±0.9 b	6.67±0.7 bc
P8	0.11±0.0 a	0.12±0.0	0.14±0.0 ab	0.13±0.0 ab	16.54±2.5 ab	15.34±0.0 ab	4.85±0.6 b	7.42±0.5 bc
Sig.	0.028	0.244	0.046	0.002	0.21	0.17	<.001	<.001
	Soil exchangeable K (me $100g^{-1}$)				Soil exchangeable Ca (me $100g^{-1}$)			
P0	0.26±0.0 a	1.08±0.5	0.36±0.0 ab	0.37±0.0 b	3.69±1.1	5.48±0.2 d	6.73±0.6 bc	6.11±0.3 c
P1	0.30±0.0 ab	0.27±0.0	0.27±0.0 a	0.27±0.0 a	3.93±0.3	2.95±0.1 a	4.26±0.4 a	5.52±0.3 c
P2	0.46±0.0 c	0.31±0.0	0.30±0.0 ab	0.40±0.0 bc	5.17±0.7	3.60±0.3 b	5.01±0.7 ab	6.09±0.2 c
P3	0.39±0.0 bc	0.37±0.0	0.39±0.1 bc	0.37±0.0 b	4.04±0.7	3.60±0.2 b	7.85±0.8 c	6.27±0.2 c
P4	0.45±0.0 c	0.47±0.0	0.44±0.0 c	0.41±0.0 c	4.02±0.7	4.57±0.2 c	5.36±0.8 ab	6.05±0.2 c
P5	0.28±0.0 a	0.29±0.0	0.27±0.0 a	0.24±0.0 a	4.41±0.7	4.57±1.1 bcd	5.24±0.5 ab	4.26±0.1 b
P6	0.43±0.0 c	0.35±0.0	0.32±0.0 ab	0.32±0.0 b	4.58±0.2	4.71±0.4 c	4.35±0.4 a	3.28±0.2 a
P7	0.39±0.0 bc	0.43±0.0	0.57±0.0 d	0.36±0.0 b	4.80±0.3	3.60±0.1 b	4.56±0.7 a	3.06±0.1 a
P8	0.46±0.0 c	0.47±0.0	0.49±0.0 d	0.44±0.0 c	4.26±0.2	4.77±0.4 c	5.05±0.6 ab	3.80±0.3 ab
Sig.	<.001	0.14	<.001	0.003	0.77	0.03	0.004	<.001

Note: P0 = Control (P0); P1 – P4 = Fine compost with dose 0.29 g (~2 tons ha^{-1}); 0.58 g (~4 tons ha^{-1}); 1.16 g (~8 tons ha^{-1}); 1.74 g (~12 tons ha^{-1}); P5 – P8 = Granule compost with dose 0.29 g (~2 tons ha^{-1}); 0.58 g (~4 tons ha^{-1}); 1.16 g (~8 tons ha^{-1}); 1.74 g (~12 tons ha^{-1}); Means ± s.e.d followed by different lowercase letters indicate significant differences among treatments (analysis of variance with Duncan test at $P \leq 0.05$); WAI = week after incubation.

In Inceptisol (Table 3), the application of different forms and doses of coffee fruit husk compost gave a significant effect (p = 0.001 – 0.04) on soil pH (especially at 4-weeks after incubation / WAI), soil organic C (at 2-WAI), soil exchangeable K (at 1, 2 and 4-WAI), and soil exchangeable Ca (at 1, 2, 4, and 8-WAI). In addition, the research was unable to detect significantly different ($p > 0.05$) among different treatment of coffee fruit husk compost on total N and soil available P during 8-weeks incubation (Table 3). This was probably due to the immobilization process by soil microorganism, N loss through volatilization, and the high P bound by allophane mineral. In addition, Al-Batania [32] reported that the low N released from compost application was also affected by the age of compost which might influence the rate of N mineralization. Then, population of nitrogen-fixing and phosphate solubilizers bacteria were increased by the length of composting [33]. Comparing between fine and granule composts of coffee fruit husk in all application dose within Inceptisol, the study generally recorded that application of granule compost (treatment P5 – P8) resulted a lower soil pH, soil exchangeable K and Ca on 4-weeks after incubation as compared to fine compost (treatment P1 – P4) application (Table 3). This finding indicated that granule compost more slowly decomposed as compared to fine compost, consequently releasing low base cations (i.e., K and Ca) and resulting in lower soil pH. The increased application dose of coffee fruit husk compost increased soil exchangeable K and Ca at 2-WAI, especially in the granule compost (Table 3). Coffee fruit husk compost contains an amount of nutrient (i.e. N, P, K, Ca), and therefore the increased application doses of compost was followed by the increases of soil exchangeable base cations (i.e. K and Ca). The highest soil exchangeable K and Ca were reached by application 1.44 – 2.16 g (~8 to 12 tons/ha) of coffee fruit husk compost. Our findings correspond to the previous research by Adekiya et al. [34] who reported that the increases rate of poultry manure application up to 5 t ha^{-1} resulted in increased soil organic matter, N, P, K, Ca and Mg. Further, another study reported a linear increase of soil exchangeable Ca, P dan K with the increases of compost application doses from 0, 35, 70, 105, 140, and 175 tons/ha [35].

In the Entisol – Malang regency, Indonesia (Table 4), differences in the form of coffee fruit husk compost (such as fine and granule) have a significant effect (p = 0.001 to 0.046) on soil pH, soil organic C, total N and soil available P, and soil exchangeable base cations (e.g., K and Ca) during 8-week incubation research. Soil pH, soil organic C, and soil exchangeable Ca were higher in the application of fine compost than those in the granule compost (Table 4). Ayilara et al. [36] stated that the rate of compost decomposition increases if the particle size decreases because the smaller size of compost has higher surface area and increased microbial activity. Furthermore, the effect of the increases application dose of coffee fruit husk compost on soil nutrient content was found only for soil exchangeable K during 4 and 8 weeks incubation (Table 3). Lanna et al. [35] reported the quadratic effect of the compost application dose on K in the soil where that the excessive application doses of compost was not followed by the increased potassium in the soil.

3.3. Effect of Application of Coffee Fruit Husk Compost on Radish Cultivation

In general, soil in the field experiment had a silty loam texture and low soil fertility. This was shown by the laboratory measurement prior to field experiment (Table 5) which showed that the soil had an acidic soil pH, and the low soil nutrient content (e.g., available P, soil exchangeable Na, Ca, and Mg). The low soil available P was probably due to the soil in UB Forest derived from volcanic ash material with allophane mineral having a high capacity in P bound. Whereas the low soil exchangeable Na, Ca, and Mg, as well as an acidic soil pH indicated the high base cations leaching in the study area. Putri et al. [19] reported that soil chemical variation in UB Forest was affected by land-uses systems which is related to differences in soil management practices in particular fertilization. Total N in our plot was slightly higher than Sudharta et al. [37], who recorded that total soil nitrogen at a depth of 0-10 cm and 10-20 cm across four coffee-pine agroforestry management in UB Forest ranged from 0.39 – 0.46 g/100g. Therefore, the application of coffee fruit husk compost is expected to increase plant growth and production.

Table 5. Soil characteristics before application coffee fruit husk compost

Variable measured	Unit	Value	Criteria*
pH H_2O	-	5.1	Acid
pH KCl	-	4.8	-
Soil organic C	%	5.53	Very high
Total N	%	0.50	Medium
Available P	ppm	1.67	Very low
K-exc.	$mmol_{charge}$/100 g	0.41	Medium
Na-exc.	$mmol_{charge}$/100 g	0.23	Low
Ca-exc.	$mmol_{charge}$/100 g	4.84	Low
Mg-exc.	$mmol_{charge}$/100 g	0.86	Low
Sand	%	19	
Silt	%	70	
Clay	%	11	
Soil texture	-	Silty loam	

*Criteria based on Indonesian soil research instutute [26]

Table 6. Effect of different types and doses of coffee fruit husk compost on root yield variables of radish

Treatment	Root length (cm)	Root diameter (cm)	fresh weight of root per plant (g/plant)	root yield (kg/m^2)	root yield (kg/plot)	Agronomic efficiency
P1D1	36.33±0.7 a	4.54±0.2 a	261.44±5.2 a	6.54±0.1 a	20.92±0.4 a	-
P1D2	38.56±0.6 b	4.89±0.1 ab	270.39±16.3 a	6.76±0.4 a	21.63±1.3 a	0.35±0.3
P1D3	39.22±0.0 b	4.74±0.1 ab	276.00±11.8 a	6.90±0.3 a	22.08±0.9 a	1.71±1.1
P1D4	39.33±0.7 b	4.89±0.1 ab	292.56±8.2 ab	7.31±0.2 ab	23.40±0.7 ab	0.41±0.2
P1D5	39.94±1.1 b	5.01±0.0 b	302.22±6.4 ab	7.56±0.2 ab	24.18±0.5 ab	0.40±0.1
P2D2	38.83±1.1 b	4.77±0.1 ab	268.17±16.1 a	6.70±0.4 a	21.45±1.3 a	0.71±0.5
P2D3	38.67±0.4 b	4.82±0.1 ab	292.11±29.4 ab	7.30±0.7 ab	23.37±2.4 ab	1.26±0.7
P2D4	42.44±0.7 c	5.79±0.2 c	499.00±15.1 c	12.48±0.4 c	39.9±1.2 c	2.88±0.2
P2D5	38.61±0.5 b	5.02±0.1 b	340.72±13.5 b	8.52±0.3 b	27.26±1.1 b	0.85±0.1
Sig.	< 0.01	< 0.01	< 0.01	<.001	<.001	0.16

Note: P1D1 = Control = 0 kg/plot (~ 0 tons/ha), P1D2 = fine compost with doses 0.9 kg/plot (~3 tons/ha), P1D3 = fine compost with doses 1.8 kg/plot (~6 tons/ha), P1D4 = fine compost with doses 2.7 kg/plot (~9 tons/ha), and P1D5 = fine compost with doses 3.6 kg/plot (~12 tons/ha), P2D2 = granule compost with doses 0.9 kg/plot (~3 tons/ha), P2D3 = granule compost with doses 1.8 kg/plot (~6 tons/ha), P2D4 = granule compost with doses 2.7 kg/plot (~9 tons/ha), and P2D5 = granule compost with doses 3.6 kg/plot (~12 tons/ha); Means ± s.e.d followed by different lowercase letters indicate significant differences among treatments (analysis of variance with Duncan test at P ≤ 0.05), WAI = week after incubation

Application of different types (fine and granule) and doses (0.9, 1.8, 2.7, 3.6 kg/plot ~ 3, 6, 9, 12 tons/ha) of coffee fruit husk compost was strongly affected ($p < 0.001$) radish production (i.e. root length, root diameter, root fresh weight, and root yield). Table 6 showed that application of granule compost from coffee fruit husk with a dose 2.7 kg/plot (P2D4) gave the highest radish production (i.e., root length, root diameter, fresh weight of root, and root yield) as compared to the other treatments (i.e., control, fine compost with dose 0.9, 1.8, 2.7, 3.6 kg/plot, and granule compost with dose 0.9, 1.8, 3.6 kg/plot). In addition, the production of radish (i.e., root length, root diameter, fresh weight of root, and root yield) with application of 2.7 kg granule compost/plot (P2D4) was 19 to 98% higher than control, and 6 to 86% higher than the other dose of coffee fruit husk compost. As consequence, agronomic efficiency in the application of 2.7 kg granule compost per plot tended to be higher than the other treatment (Table 6). The highest radish production in application of 2.7 kg granule compost per plot was probably due to that the granule compost was slowly decomposed, as a consequence providing longer nutrients release than fine compost. In addition, the effect of nutrient released from mineralization on plants was also dependent on the synchrony between the decomposition and mineralization of the compost and the period of highest nutritional demand of the crop.

Root length and total root yield of radish by applying 2.7 kg granule compost of coffee fruit husk/plot (P2D4) reached 42.4 cm and 12.5 kg/m^2 (Table 6). These results were higher than those in Adekiya et al. [34] who reported that root length and root yield of radish from application biochar and poultry manure during 2015 and 2016 were 15.76 – 18.2 cm and 0.78 – 0.98 kg/m^2. In addition, root yield per plot by application of coffee fruit husk compost, which ranged from 20.92 – 39.9 kg/plot (~31.5 – 58.6 tons/ha), was also higher than root yield by application of 150 kg N/ha with 10 cm spacing (the plot size 4.5 m x 1.5 m) which reached 16,6 kg/plot and 24.6 tons/ha [38]. This was probably due to that compost / organic matter not only supplies nutrient but also improves soil physic and biology resulting in good medium for plant growth and production. However, our result of root yield (~31.5 – 58.6 tons/ha) was lower than Jilani et al. [39] who reported the root yield of radish ranged from 60.3 – 99.9 ton/ha (the plot size was 1,5 m x 3 m). Overall, the result confirmed that coffee fruit husk compost is potentially used as organic fertilizer for improving crop production and agronomic efficiency.

4. Conclusions

Coffee fruit husk as one of organic residues in coffee agroforestry systems could be managed as organic fertilizer in the form of fine and granule compost. Application of coffee fruit husk compost significantly improved soil pH, soil nutrient content, and crop production. Granule compost was more slowly decomposed as compared to fine compost, consequently releasing low base cations (i.e., K and Ca) and resulting in lower soil pH during 8-week incubation research. While, in the field research, application of granule compost especially with a dose 2.7 kg/plot (~9 tons/ha) resulted in 39.9 kg/plot (~ 58.6 tons/ha) of radish root yield or 98% higher than control and 46% - 86% higher than the other doses of coffee fruit husk compost. Overall, this study found soil fertility and agronomic benefit of coffee fruit husk compost application as organic fertilizer or soil ameliorant.

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