

Research article

The Properties of Rice Stubble Compost and Its Effects on Okra Yield (*Abelmoschus esculentus* L.), Nutrient Activation Coefficient, and Organic Carbon Fractions in Soil

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Abstract

Rice stubble is an important agricultural waste product in Thailand. Using the rice stubble to make a compost is an effective way to dispose of this material as a lot of rice stubble is needed to make compost. The aim of this study was to investigate the relationship between rice stubble and other materials such as rock phosphate and cow dung on the properties of the compost and its effects on okra yield and soil properties after harvest. The results showed that the different proportions of rice stubble, rock phosphate and cow dung had an effect on the compost properties, with the compost formulation CP4 (40% rice stubble: 30% rock phosphate: 30% cow dung) showing the best properties. Varying the components of the compost formulations had no effect on pod yield and N and P uptake but these properties were significantly different when compared to the control. The application of compost helped to improve soil properties after planting. In particular, the compost formulation CP4 resulted in a higher available P content (97.1 mg/kg) in the soil than the other treatments. The application of compost increased the nutrient activation coefficient, particularly the phosphorus activation coefficient (PAC). It also increased the active carbon pool, especially the very labile carbon, which can easily release nutrients to the plants. The results suggested that reducing rice stubble and increasing rock phosphate and cow dung could improve compost properties. In addition, the use of rice stubble compost enhanced soil fertility, PAC, and active carbon content in the soil.

Keywords: rice stubble compost; okra yield; soil properties; nutrient activation coefficient; carbon fraction

1. Introduction

Compost is a fertilizer obtained from the decomposition of plant or animal residues by microorganisms and become compost materials. Various materials such as water hyacinth, activated sludge or agricultural waste are used to produce compost. In Thailand, rice stubble is a good choice for the production of compost, as in 2025 there were around 9.4

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million hectares available for rice cultivation spread across all regions of the country (Rice Department, 2025). Sukyankij et al. (2023) specified that one hectare of rice field produces about 10 tons of rice stubble. Therefore, there are more than 94 million tons of rice stubble in the country every year, which is a large amount and in general they are burned by farmers to dispose of the stubble, a practice that leads to increased air pollution and the emission of gases such as CO₂, CH₄, CO, NO₂ and SO₂ (Gajbhiye et al., 2025). Rice stubble usually has a low content of plant nutrients and a carbon-rich structure that is difficult to decompose (Gajbhiye et al., 2025; Zayed & Abdel-Motaal, 2025). Therefore, when making compost from rice stubble, other materials are mixed with it to increase the content of plant nutrients and accelerate the decomposition process. Stover from sun hemp, mung beans, soybeans or manure (from cows, chickens or sheep) can be mixed with stubble as these materials are rich in plant nutrients, especially nitrogen (Faassen & Dijk, 1987; Sinkumkoon et al., 2015; Adekiya et al., 2019). Rock phosphate is also mixed with rice stubble as it contains a lot of phosphorus (Zayed & Abdel-Motaal, 2025). These materials can improve the properties of rice stubble compost. However, it is well known that using compost helps improve various soil properties, such as soil organic matter content and available plant nutrients in the soil. Soil organic matter is an important factor used to indicate soil fertility and is based on the organic carbon in the soil (SOC). Therefore, applying compost directly increases the SOC in soil. Grigatti et al. (2024) studied the effect of applying different types of compost on SOC and soil quality. They reported that the application of green waste compost could increase the amount of SOC, both in the form of non-labile C (NLC) and labile C (LC) more than the addition of chemical fertilizer or no application. In addition, Moharana et al. (2020) studied the application of compost from crop residue on SOC fractions and nitrogen in subtropical India. They found that SOC fractions were mostly present as NLC, followed by less labile C (LLC), very labile C (VLC), and LC, respectively. The application of compost from crop residues (rice straw, mustard stover, and tree leaves) improved the VLC fraction. Regarding the VLC, this fraction is important because it can release nutrients for plant uptake (Hazra et al., 2018).

Okra (*Abelmoschus esculentus* L.) is a popular vegetable for health-conscious people and is cultivated in the tropics and subtropics of the world. The fruits of okra are the main source of vitamin C, A and folic acid (Adekiya et al., 2019). They are also rich in antioxidants, as they have a high content of polyphenols, flavonoids and quercetin (Elkhalifa et al., 2021). Okra is an important export vegetable in Thailand. In 2022, around 2,911 tons of okra were exported, which corresponds to a value of 6.69 million US dollars. Most of the cultivation areas are located in the center of the country, such as in the provinces of Suphan Buri, Kanchanaburi, Ratchaburi and Nakhon Pathom, with a total cultivation area of over 580 hectares and an average yield of 8.37 t/ha (Department of Agriculture, 2022). Some reports indicate that the yield of okra can increase to over 10 t/ha with optimal nutrient management (Adekiya et al., 2019; Akter et al., 2020). In Thailand, farmers have relied mainly on chemical fertilizers for five decades, which has led to resource degradation. Examples are the long-term application of ammonium fertilizer, which over-acidifies the soil, and the frequent use of certain fertilizers such as potassium chloride, which leads to increased salt accumulation in the soil. In contrast, the use of organic fertilizers such as compost can be a better alternative to maintain crop yields, increase soil fertility and organic matter (Surin et al., 2019). In particular, there are some reports showing that okra responded better to organic fertilizers than to chemical fertilizers (Abbas et al., 2019). Adekiya et al. (2019) clearly indicated that applying organic fertilizer made from mesquite or neem leaves could increase okra yield by about 33.8-52.7% compared to chemical fertilizers (NPK) and by about 175-213% compared to the control. Besides, the increase in okra yield was also related to the amount of compost applied.

Dada and Adejumo, (2015) studied the effect of compost application on the growth and yield of okra under different light intensities and reported that okra responded well to compost application, with 15 tons/ha of compost producing higher yields than applications of 5 or 10 tons/ha. However, several studies in Bangladesh, India and Guyana suggested that applying compost together with chemical fertilizer resulted in the highest okra yields (Akter et al., 2020; Acharya et al., 2024). The hypothesis of this work was therefore that different substrates (rice stubble, rock phosphate and cow dung) used to make compost would be an influence on the properties of the compost and that the application of different compost formulations would lead to a change in growth, okra yield or soil properties. Thus, the aim of this study was therefore to investigate the effects of different rice stubble composts on the growth and yield of okra and on soil properties after harvesting.

2. Materials and Methods

2.1 Experiment 1: Compost test

2.1.1 Experimental design

The preparation of compost for the experiment was conducted from November 2023 to February 2024 at the Department of Agriculture, Faculty of Science and Technology, Phranakhon Si Ayutthaya Rajabhat University, Phra Nakhon Si Ayutthaya, Thailand. Four treatments (formulations of compost) and three replicates were used to study the efficacy of compost blends. Rice stubble, rock phosphate, and cow dung were mixed in varying quantities by weight to produce the compost (Table 1). The properties of the materials used to produce compost are shown in Table 2. The mixture was composted in the basket for 90 days, with the total amount in each treatment being 50 kg/basket. All treatments were turned every 15 days after fermentation, and 10 L of molasses (20% v/v) were added to the mixtures on days 1, 14, 30, 45, 60, and 75 after decomposition. After 90 days, a compost sample was taken from each basket to analyze its properties.

2.1.2 Data collection and analysis

The data in this section analyze the properties of the compost according to the Thai standard method (Land Development Department, 2020). The details of the analysis were that pH was measured with a pH meter at a 1:2 compost-to-distilled water ratio, and electrical conductivity was measured with an EC meter at a 1:10 compost-to-distilled water ratio. Organic carbon was determined by wet oxidation and then multiplied by 1.724 to obtain the value of organic matter. Total nitrogen (N) involved digestion with a H_2SO_4 - Na_2SO_4 -Se mixture, distillation and titration with standard sulfuric acid. Total phosphorus (P) and potassium (K) involved digestion with an acid mixture (HNO_3 : HClO_4 in a ratio of 2:1 v/v.). The clear solution was determined for total phosphorus using the vanadomolybdate yellow color method and total potassium using the flame atomic absorption spectrophotometer. The carbon/nitrogen ratio was calculated using the values of organic carbon and total nitrogen.

Table 1. The details of the materials used for the production of compost

Treatments	The Mixture for Produced Compost (% w/w)		
	Rice Stubble	Rock Phosphate	Cow Dung
CP1	70	15	15
CP2	60	20	20
CP3	50	25	25
CP4	40	30	30

Table 2. The properties of materials used to produce compost

Properties	Unit	Rice Stubble	Rock Phosphate	Cow Dung	Molasses
pH (1:5)	-	6.92	7.92	7.17	4.71
EC (1:5)	dS/m	3.29	0.23	6.73	6.54
Organic carbon	%	75.4	ND	25.5	20.2
Total nitrogen	%	0.32	ND	1.02	0.55
Total phosphorus	%	0.19	7.51	0.85	0.08
Total potassium	%	1.66	0.67	1.32	3.27
C/N ratio	-	239	-	25.0	36.7

Notes: ND-not detected

2.2 Experiment 2: Effect of compost on growth and yield of okra

2.2.1 Experimental design

The study on the effect of compost on the growth and yield of okra was conducted from March to July 2024 in a greenhouse at the Department of Agriculture, Faculty of Science and Technology, Phranakhon Si Ayutthaya Rajabhat University, Thailand. About 200 kg of soil (0-20 cm depth) used for the experiment was collected from farmers' fields in Bang Sai district, Phra Nakhon Si Ayutthaya province and air-dried in the greenhouse for 14 days. After the soil was completely dry, about 0.5 kg of soil was sent to test its physio-chemical properties. The properties of the soil were characterized by a clay texture, a pH of 4.65, 3.16 dS/m saturated electrical conductivity, 2.24% organic matter, 29.2 mg/kg ammonium, 4.1 mg/kg nitrate, 0.08% total nitrogen, 35.1 mg/kg available phosphorus, and 247 mg/kg exchangeable potassium. For the pot experiment, a completely randomized design (CRD) with five treatments and three replicates was used, consisting of T1 as control (no addition of compost, CK) and T2 to T5, to which the compost formulas CP1 to CP4 were added, respectively. With the exception of T1 (dried soil only), each pot was mixed with 8 kg of dried soil and 51.3 g of dried compost, which corresponded to the use of compost at the recommended rate (12.5 t/ha) (Department of Agricultural Extension, 2025) and incubated for 7 days before cultivation. After that, three seeds of commercial okra seeds (purchased from East-West Seed Group, Thailand) were placed in each pot. After 7 days of germination, the excess plants were removed, leaving 1 plant per pot. All pots were watered daily and if weeds were found in the pot, they were removed by hand to keep weed-free condition. After 55 days from sowing, the okra was harvested and was harvested continuously for up to 120 days, with the fresh yield recorded each time. At 40, 60, 80, 100, and 120 days after sowing, the leaf greenness of the okra plants was measured using a chlorophyll meter (SPAD-502 Plus) by assessing leaves 3 and 4 from the top of the plant between 9.00 to 10.00 am. The mean values were calculated before being recorded. On

the day of harvest, plant height was measured with a measuring tape from the top to the base of the plant, and stem diameter was measured with a vernier caliper, with each plant considered as one replication. All samples (pods and stover) were dried in a hot air oven at 70°C until a constant weight was reached and recorded. In addition, 200 g of soil from each pot was kept.

2.2.2 Data collection and analysis

The experimental data included measurements of nutrients in plants and some soil properties. The total contents of N, P, and K in the plant and soil samples were analyzed by crushing the samples and sieving them through a 2 mm sieve. For total N, 0.2 g of the plant or soil was digested with a H₂SO₄-Na₂SO₄-Se mixture and the N content was analyzed using the Kjeldahl method (Jackson, 1965), while for total P and K, three acid mixtures (HNO₃-H₂SO₄-HClO₄ mixture) (Johnson & Ulrich, 1959) were used for digestion, and the P and K contents were analyzed using the vanadomolybdate yellow color method (Murphy & Riley, 1962) and flame atomic absorption spectrophotometer (Shimazu, AA-7000) (Westerman, 1990), respectively. Nutrient uptake (NU) was calculated from the dry weight (DW) of the plant by multiplying it by the plant nutrient concentration (PNC) (Sukyankij et al., 2023), as shown in equation 1.

$$\text{NU (g/plant)} = \text{PNC} \times \text{DW} \quad (1)$$

For soil analysis, about 200 g of soil was collected after harvesting the plants and then air-dried, crushed and sieved through a 2 mm sieve to analyze soil properties (except organic matter, for which a 0.5 mm sieve was used). The soil pH was analyzed with a pH meter at a 1:1 ratio of soil to distilled water (Thomas, 1996). The saturated electrical conductivity of the soil was determined with an EC meter (Rhoades, 1996). Organic carbon (OC) was measured by oxidation with K₂Cr₂O₇ and titration with FeSO₄ and the OC value was then converted to organic matter (OM) by multiplication by 1.724 (constant factors) (Nelson & Sommers, 1996). The available nitrogen in soil was extracted with 2N KCl and the amount of ammonium and nitrate was determined by the stream distillation method (Mulvaney, 1996), the available P content in the soil was extracted with Bray II extractant and determined by the ascorbic acid method (Kuo, 1996) and the exchangeable K content in soil was extracted with 1M NH₄OAc at pH 7 and measured by flame atomic absorption spectrophotometry (Helmke & Sparks, 1996). The nutrient activation coefficient (NAC) was calculated from the ratio between the amount of available plant nutrient (APN) and the total plant nutrient (TPN) in the soil (Yang et al., 2019; Sukyankij et al., 2024), as shown in equation 2.

$$\text{NAC (\%)} = (\text{APN} / \text{TPN}) \times 100 \quad (2)$$

In addition, the carbon fractions (C) in the soil were also reported, which were categorized into four groups: very labile C (VLC), labile C (LC), less labile C (LLC) and non-labile C (NLC), which were determined as described by Luan et al. (2021). Each fraction was oxidized with dichromate and using different concentrations of H₂SO₄ (12N, 18N, and 24N), as shown in equations 3-6.

$$\text{VLC (\%)} = \text{organic C oxidized under 12N H}_2\text{SO}_4 \quad (3)$$

$$\text{LC (\%)} = \text{organic C oxidized under 18N H}_2\text{SO}_4 - 12\text{N H}_2\text{SO}_4 \quad (4)$$

$$\text{LLC (\%)} = \text{organic C oxidized under 24N H}_2\text{SO}_4 - 18\text{N H}_2\text{SO}_4 \quad (5)$$

$$\text{NLC (\%)} = \text{total organic C} - 24\text{N H}_2\text{SO}_4 \quad (6)$$

To evaluate the total organic C (TOC) in the soil, the dichromate oxidation method was used by heating at 130°C for 30 min (Nelson & Sommers, 1996; Fernandes et al., 2015). All calculated values of C fractions were classified as the active C pool and passive C pool by designating the sum of the VLC and LC fractions as the active C pool and the sum of the LLC and NLC fractions as the passive C pool (Nandan et al., 2019).

2.3 Statistical analysis

The results of both experiments 1 and 2 were analyzed using the software program SPSS version 22. An analysis of variance (ANOVA) was performed to determine the difference between the mean values. The differences between treatments were tested using Duncan's new multiple range test (DMRT) at the probability level of $P < 0.05$. The percentage coefficient of variation (CV, %) was calculated from the ratio of the square root of the mean squared error to the mean value and multiplied by one hundred.

3. Results and Discussion

3.1 Properties of compost

The use of different materials for the production of compost obviously showed significant differences ($P < 0.05$), except for the total nitrogen content (Table 3). Decreasing the amount of rice stubble and increasing the amount of rock phosphate and cow dung led to an increase in the pH, electrical conductivity, total phosphorus and total potassium of the compost. In contrast, the amount of organic matter, the C:N ratio and the moisture content of the compost decreased. The compost from the CP4 treatment (40% rice stubble: 30% rock phosphate: 30% cow dung) yielded the highest total phosphorus and total potassium content (1.22 and 1.16%, respectively). While the CP1 treatment (70% rice stubble: 15% rock phosphate: 15% cow dung) had the highest organic matter, C:N ratio and moisture content (32.3%, 18.7 and 48.7%, respectively).

All composts produced from the various proportions of rice stubble met the standard criteria of the Thai Department of Agriculture (Department of Agriculture, 2005), except for moisture content, which was required not to exceed 30% in organic fertilizer. However, the moisture content in compost can drop below 30% when it is air-dried before storage. The addition of higher levels of rock phosphate and cow dung could significantly increase the total phosphorus and total potassium contents in the compost, as rock phosphate has a high P content, while cow dung also contains a lot of K (Table 2). In addition, rock phosphate was important to increase the pH value of the compost, as it contains a lot of calcium compounds (CaO and CaCO_3) (Farrag & Bakr, 2023), which increases the pH value (Table 3). Zhang and Sun (2017) investigated the production of compost from different doses of fish pond sediments and rock phosphate. They found that increasing the dose of rock phosphate by up to 10-15% increased the total N, P and K content by 9.75-18.6%, 55.0-95.0% and 73.9-100%, respectively, compared to an application without rock phosphate. Meanwhile, cow dung contains many plant nutrients

and is normally used to make compost. Nguyen et al. (2024) reported that cow dung has a high nutrient content and is a valuable source of K, with most of the K in cow dung present in a water-soluble form. However, organic matter and the value of C:N ratio of the compost tended to decrease when the amount of rice stubble was reduced. The reason for this was that rice stubble contains abundant organic carbon (Nghie et al., 2020), especially the rice stubble used in this experiment (Table 2). Therefore, reducing the amount of rice stubble as an important carbon source in the production of compost led to a decrease in the amount of organic matter and the C:N ratio.

Table 3. The properties of compost from different rice stubble formulations

Treatments	pH _{1:2} [†]	EC _{1:10} (dS/m) [†]	OM (%) [†]	TN (%)	TP (%) [†]	TK (%) [†]	C:N ratio [†]	Moisture (%, w/w) [†]
CP1	6.85 ^b	2.57 ^b	32.3 ^a	1.00	0.51 ^c	0.81 ^b	18.7 ^a	48.7 ^a
CP2	7.32 ^a	2.83 ^b	30.5 ^{ab}	1.03	0.73 ^b	0.86 ^b	17.2 ^a	43.5 ^{ab}
CP3	7.33 ^a	2.87 ^b	24.2 ^b	1.05	0.98 ^{ab}	0.91 ^{ab}	13.4 ^b	36.3 ^b
CP4	7.37 ^a	3.96 ^a	22.8 ^b	1.07	1.22 ^a	1.16 ^a	12.3 ^b	32.2 ^c
F-test	*	*	*	ns	*	*	*	*
CV (%)	0.62	5.07	5.45	10.1	5.21	4.65	8.98	2.88

Notes: [†] Values with different letters in the same column differ significantly based on DMRT at P<0.05; p<0.05= *; p>0.05= ns; EC= electrical conductivity; OM= organic matter; TN= total nitrogen; TP= total phosphorus; TK= total potassium; C:N ratio= carbon per nitrogen ratio.

3.2 Effects of different composts on okra

Okra growth was evaluated by plant height, stem diameter and leaf greenness value at different days after sowing (40, 60, 80, 100 and 120 days), while okra yield was expressed by pod fresh weight. In addition, the nutrient uptake (of nitrogen, phosphorus and potassium) in the pods as well as in the stems and leaves of okra was evaluated. The application of different formulation of rice stubble compost did not differ statistically (P>0.05) in plant height and stem diameter, with both parameters ranging between 113-123 and 1.31-1.74 cm, respectively (Table 4). In addition, there was no significant difference (P>0.05) in leaf greenness on all days on which the plants were assessed (Figure 1). For yield of okra, there was a significant difference in okra yield when rice stubble compost was used compared to the control (P<0.05). However, no differences were observed between the different formulations of rice stubble compost, with the range of yields being 80.8-86.6 g FW/pot (Table 4).

The application of rice stubble compost had an explicit effect on increasing okra yield because the application of fertilizer to plants is an important key to successful crop production. It increases crop productivity by replenishing the soil with essential nutrients, thus supporting plant growth, maximizing agricultural yields and ensuring global food security (Asadu et al., 2024). However, all compost formulations contained levels of N, P, and K that met the standard criteria for organic fertilizer (Department of Agriculture, 2005). This may be an important reason why applying all compost formulations provided optimal plant nutrients for okra. The difference in okra yield between the use and non-use of

compost was clearly observed. The results of the experiment showed that all treatments receiving the compost produced a higher pod yield than the control. Although there were no significant differences in plant height, stem diameter and leaf greenness, it was shown that the application of rice stubble compost had a better effect on growth than the non-application of compost. This was especially true for the value of stem diameter (Table 4) and the value of leaf greenness at the 100 and 120 days after planting (Figure 1). Several reports confirmed the effectiveness of fertilizers, especially organic fertilizers, in increasing crop yields (Abbas et al., 2019; Widowati et al., 2020; Hossain & Islam, 2024). Besides, Acharya et al. (2024), who studied the application of four different types of vermicompost on the productivity of okra in Nepal, showed that there was no significant difference in yields when vermicompost was applied with different types, but there was a significant difference when vermicompost was not applied. However, the application of organic fertilizer alone did not produce plants of the highest yields, in fact, the application of organic fertilizer in combination with chemical fertilizer led to the highest crop yields. Benchasri et al. (2021) studied the influence of fertilizer type on the growth and yield of okra in southern Thailand and reported that the use of organic fertilizer (swine manure) resulted in the highest okra yield, which was 28.1% higher than with chemical fertilizer (conventional cultivation) and 441% higher than with no fertilizer (control). According to our results, applying compost increased okra yield by approximately 41.3-51.4% compared to the control. Abbas et al. (2019) investigated the influence of compost, poultry manure and NPK fertilizers on okra yield and found that the combination of poultry manure and half NPK dose (75:37.5:30 kg N-P-K/ha) was able to increase okra yield by about 57.0% compared to the full NPK dose, while the application of compost was also able to increase yield by about 33.1%. Some reports also stated that the combination of compost and biochar can increase crop yields. Widowati et al. (2020) investigated the effect of biochar and organic fertilizer on increasing maize yield on different types of drylands in Indonesia and reported that compost application significantly increased maize yield compared to the control and that this treatment was also not significantly different from the yield of the highest yielding treatment.

Table 4. Growth and yield of okra plants under the influence of different rice stubble composts

Treatments	Plant Height (cm)	Stem Diameter (cm)	Pod Yield (g FW/plant) [†]
CK	120	1.31	57.2 ^b
CP1	123	1.73	83.4 ^a
CP2	113	1.74	84.0 ^a
CP3	114	1.62	86.6 ^a
CP4	117	1.73	80.8 ^a
F-test	ns	ns	*
CV (%)	8.69	15.3	12.9

Notes: [†] Values with different letters in the same column differ significantly based on DMRT at $P < 0.05$; $p < 0.05 = *$; $p > 0.05 = ns$; CK= control treatment

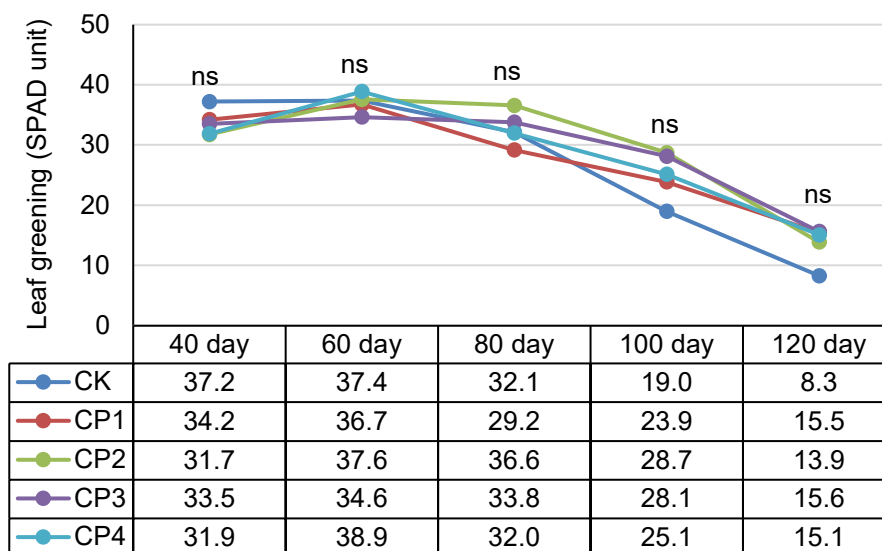


Figure 1. Leaf greenness of the okra plants under the influence of different rice stubble compost in different age periods; $p>0.05$ = ns; CK= control treatment

The nutrient uptake of okra was measured only for the primary plant nutrients (N, P and K) in the pods and in the stover tissue (Table 5). In particular, N uptake in all tissues and only P uptake in the pods differed significantly ($P<0.05$) with the application of compost fertilizer. The application of rice stubble compost clearly produced an uptake of N and P in okra (2.37-2.62 g/plant for total N uptake and 0.17-0.19 g/plant for pod P uptake) that was higher than okra without compost application (1.67 g/plant for total N uptake and 0.14 g/plant for pod P uptake), while the use of different rice stubble compost formulations (CP1-CP4) showed no difference in N and P uptake in the plant. There was no statistical difference in K uptake between pods, stover, and total uptake. However, the main reason that no significant difference was found in K uptake by the plant may be that the soil K level (247 mg/kg) before planting okra was high (Land Classification Division and FAO Project Staff, 1973). Therefore, there was no difference between treatments with or without compost application.

Compost is an important source of plant nutrients, especially in this experiment where no nutrients were added from other sources. Treatment with compost therefore has the effect of increasing the nutrient uptake of the plants. Added compost can delay the loss of applied plant nutrients, possibly help to retain soil moisture and slowly release some plant nutrients through mineralization so that the nutrients are available during the growth phase of the plants (Rann et al., 2016). Rann et al. (2016) studied the response of rice to pig manure and chemical fertilizer in Thailand and found that the application of pig manure could increase the nutrient uptake (NPK) of the rice plant. This treatment produced an NPK that was close to the application of 50% pig manure in combination with a full dose of chemical fertilizer, which caused the highest nutrient uptake by the plant. Adewole and Ilesanmi (2011) studied the effect of soil amendments on nutrient quality of okra and reported that the use of organic compost fertilizer significantly increased N, P and K content compared to inorganic fertilizer, biofertilizer, or without fertilizer application.

Table 5. Nutrient uptake (N, P, K) in pod and stover of okra under the influence of different rice stubble composts

Treatments	N Uptake (g/plant)			P Uptake (g/plant)			K Uptake (g/plant)		
	Pod [†]	Stover [†]	Total [†]	Pod [†]	Stover	Total	Pod	Stover	Total
CK	0.46 ^b	1.21 ^b	1.67 ^b	0.14 ^b	0.40	0.53	0.39	0.99	1.39
CP1	0.59 ^a	2.03 ^a	2.62 ^a	0.17 ^a	0.56	0.72	0.47	1.01	1.48
CP2	0.64 ^a	1.73 ^a	2.37 ^a	0.19 ^a	0.46	0.65	0.47	0.86	1.33
CP3	0.57 ^a	1.95 ^a	2.52 ^a	0.17 ^a	0.45	0.62	0.46	1.05	1.51
CP4	0.59 ^a	1.90 ^a	2.49 ^a	0.18 ^a	0.44	0.61	0.51	1.03	1.54
F-test	*	*	*	*	ns	ns	ns	ns	ns
CV (%)	8.4	14.9	12.2	9.9	22.2	16.8	9.7	13.7	9.2

Notes: [†] Values with different letters in the same column differ significantly based on DMRT at $P < 0.05$; $p < 0.05 = *$; $p > 0.05 = ns$; CK= control treatment

3.3 Soil properties after harvesting

The application of rice stubble compost led to a change in some soil parameters but only soil pH, ammonium and available P were significantly different ($P < 0.05$) (Table 6). The application of CP4 compost (40% rice stubble: 30% rock phosphate: 30% cow manure) resulted in the highest soil ammonium and available P contents, which were 28.0 and 97.1 mg/kg, respectively, while CP3 compost (50% rice stubble: 25% rock phosphate: 25% cow manure) resulted in the highest soil pH. However, the application of compost (CP1-CP4 formulations) did not differ significantly in ammonium content, which ranged between 22.1-28.0 mg/kg (Table 6). The application of compost had a positive effect on some soil properties such as the pH value of the soil. This was because the rock phosphate in the composition of the compost has an influence on increasing soil pH. In general, the application of compost can also increase the pH, porosity, moisture, aggregate stability, organic content, P and K content and reduce the bulk density of the soil (Ho et al., 2022). In this experiment, we observed that the treatment with compost resulted in a significantly higher soil pH than the control, and this is an important factor for increasing the mineralization of nutrients in the soil (Ho et al., 2022). The amount of ammonium was significantly increased in the treatment with compost application compared to the control, indicating a positive effect of compost application. According to Mahmood et al. (2017), who studied the effect of organic and inorganic fertilizer on maize yield and soil properties, the application of organic fertilizer apparently provided the highest total N content in the soil after maize cultivation, and this treatment also gave higher soil N than the inorganic fertilizer treatment. Normally, compost is a source of plant nutrients, especially nitrogen. Cahyani et al. (2024) reported that compost from rice stubble had a N content between 1.34 to 1.67%, depending on the material used to mix with rice stubble, with this value being quite close to the result of the experiment (1.00 to 1.07%) (Table 3). This directly affected the increase in soil ammonium content after planting compared to the control (Table 6). Regarding the available P in the soil, the main reason for the increase of available P in the soil after planting is probably the rock phosphate contained in the compost. The results showed that the application of compost with a high content of rock phosphate led to an increase in the available P content in the soil and the amount of available P in the soil increased with increasing rock phosphate content in the compost. Billah et al. (2020) evaluated the effects of compost enriched with rock phosphate and rhizobacteria for soil health and wheat yield. They found that the application of compost with rock phosphate and rhizobacteria increased the available P content in the soil after wheat cultivation to a greater degree than the control or normal compost.

Table 6. The properties of the soil after harvesting the okra plant under the influence of different rice stubble composts

Treatments	pH _{1:1} [†]	EC _e (dS/m)	OM (%)	NH ₄ ⁺ (mg/kg) [†]	NO ₃ ⁻ (mg/kg)	Avail. P (mg/kg) [†]	Exch. K (mg/kg) [†]
CK	4.92 ^c	3.61	2.94	18.6 ^c	2.92	39.6 ^d	154
CP1	5.47 ^b	3.73	3.28	26.6 ^a	7.00	46.2 ^d	197
CP2	5.69 ^{ab}	3.79	3.23	22.1 ^{ab}	5.83	64.6 ^c	203
CP3	6.01 ^a	3.46	3.21	27.8 ^a	8.17	80.1 ^b	199
CP4	5.81 ^{ab}	3.44	3.32	28.0 ^a	8.17	97.1 ^a	216
F-test	*	ns	ns	*	ns	*	ns
CV (%)	3.05	4.64	7.27	15.4	36.2	11.32	16.79

Notes: [†] Values with different letters in the same column differ significantly based on DMRT at P<0.05; p<0.05= *; p>0.05= ns; CK= control treatment.

Rice stubble compost application affected the increase in nutrient activation coefficient (NAC) for all plant nutrients (N, P, K), but only the phosphorus activation coefficient (PAC) was significantly different (P<0.05) (Figure 2). The application of CP4 compost resulted in the highest PAC value (7.52%), which was not significantly different from CP3 compost (7.38%), and the control treatment resulted in the lowest PAC value (5.75%). However, increased the amount of rock phosphate resulted in a clear increase in total P in the compost, with CP2, CP3, and CP4 having total P levels higher than CP1 by approximately 47.1%, 92.1%, and 139.2%, respectively (Table 3). This result directly increased soil available P, with the experiment indicating that the amount of available P in the soil tended to increase more than soil available N and K (Table 6). This was an important reason why the application of compost had a significantly greater effect on the PAC than on the N and K activation coefficients. The results for the N and K activation coefficients showed no significant differences, with values ranging between 2.22-3.20% and 3.86-5.40%, respectively. In this study, NAC was determined to assess the efficiency of rice stubble compost in enhancing the conversion of total soil nutrients into plant-available forms (Sukyankij et al., 2025). It is an important indicator of soil fertility. The higher the NAC value, the more plant nutrients are available for plant growth (Wu et al., 2017; Yang et al., 2019). The results showed that the application of compost increased NAC in all primary plant nutrients. This is because compost is a good source of plant nutrients and can improve physical and chemical soil quality. When compost is added to the soil, the physical, chemical and biological properties of the soil improve (Ho et al., 2022). It promotes the conversion of plant nutrients from the total form to the available form, which is an important reason for increasing NAC.

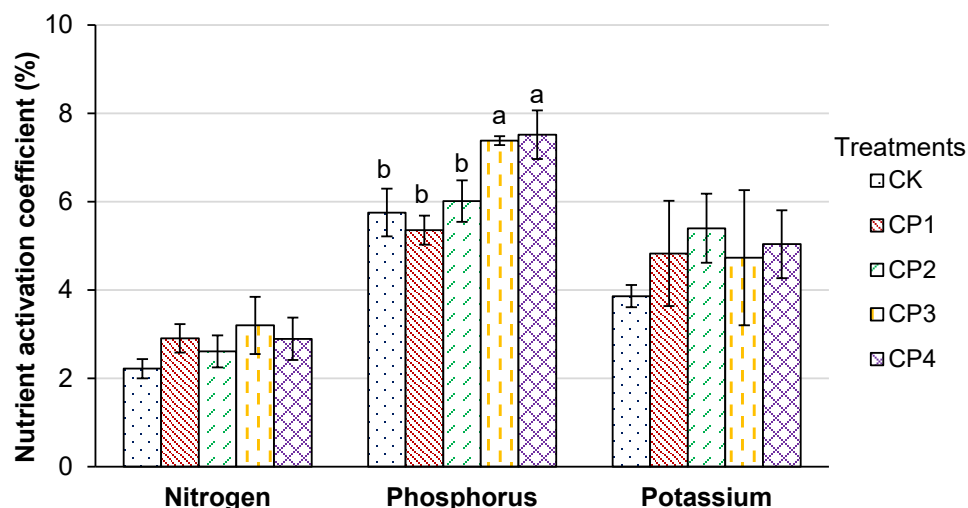


Figure 2. Nutrient activation coefficient (NAC) of nitrogen, phosphorus and potassium under the influence of different rice stubble composts

The carbon fractions of the soil differed significantly ($P < 0.05$) only for the very labile carbon (VLC) and the less labile carbon (LLC). The active carbon pool (AC-P) was also significantly different (Table 7). The compost formulation with a low proportion of rice stubble tended to increase the VLC, with the CP4 compost having the highest value (1.71%). On the other hand, the low proportion of rice stubble in the compost explicitly led to a decrease in LLC, with the control treatment showing the highest value (1.01%). Furthermore, the reduction in the proportion of rice stubble in the compost produced led to an increase in the AC-P, with the CP4 compost treatment having the highest AC-P value (2.97%), which was not significantly different from other compost treatments. In general, AC-P (VLC plus LC) are recognized as important markers of soil quality, as these C pools directly influence plant nutrient supply and crop yield, and the active C pool can change more significantly depending on cultivation and soil management (Hazra et al., 2018). The results showed that the application of compost increased the C pool in the form of AC-P. This meant that treatment with compost could release more plant nutrients than without application. The control treatment had the highest passive C pool (PC-P), and this suggested that when compost or organic residues were not applied, the C pool in the soil tended to change from AC-P to PC-P, representing C stabilization (LLC plus non-labile C, NLC). According to Moharana et al. (2020), the application of compost from mustard stover and tree leaves increased AC-P compared to control, and this increase was greater when the compost was applied together with half the recommended rate of chemical fertilizer. The type of compost influences the amount of SOC in the soil. Grigatti et al. (2024) found that green waste compost could provide higher TOC and PC-P than other composts including anaerobically digested bio-waste, sludge, and bio-waste, while the content of AC-P was more influenced by the quantity of compost applied than by the type of compost. However, the addition of compost or organic residues to the soil is therefore important as they are a source of available C in the soil, which plays a role in releasing nutrients for plants (Hazra et al., 2018).

Table 7. The difference in C fractions under the influence of different rice stubble composts

Treatments	Carbon Fractions (%)				Interpretation	
	VLC [†]	LC	LLC [†]	NLC	AC-P (%) [†]	PC-P (%)
CK	0.37 ^c	0.83	0.59 ^a	0.78	1.20 ^b	1.37
CP1	0.84 ^b	0.79	0.35 ^b	0.84	1.63 ^a	1.19
CP2	0.87 ^{ab}	0.72	0.10 ^c	0.95	1.59 ^a	1.05
CP3	0.99 ^a	0.72	0.06 ^c	1.02	1.71 ^a	1.08
CP4	0.99 ^a	0.73	0.10 ^c	0.98	1.72 ^a	1.08
F-test	*	ns	*	ns	*	ns
CV (%)	8.18	7.18	23.5	13.2	5.09	9.76

Notes: † Values with different letters in the same column differ significantly based on DMRT at $P < 0.05$; $p < 0.05 = *$; $p > 0.05 = ns$; CK= control treatment; VLC= very labile C; LC= labile C; LLC= less labile C; NLC= non-labile C; AC-P= active C pool; PC-P= passive C pool

4. Conclusions

The different proportions of the materials used to produce compost influenced the properties of the compost. The use of a low proportion of rice stubble and a higher proportion of rock phosphate and cow dung led to better compost properties. Application of rice stubble compost resulted in a significantly higher pod yield and higher N and P uptake than without application, however, no significant difference was found among the use of the different compost formulations. The soil properties after planting, however, differed significantly, especially with regard to ammonium and available P, while only the NAC value showed significant differences, especially for PAC. In addition, the application of rice stubble compost increased the active C pool, which is an important source of plant nutrients, suggesting that the addition of compost helps to increase the availability of nutrients to plants.

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6. Authors' Contributions

Saychol Sukyankij designed the research, conducted the research, analyzed the data, coordinated the research and wrote the paper.

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7. Conflicts of Interest

No conflicts of interest.

References

- Abbas, Z., Mubashir, M., Riaz, U., Javid, Z., Ashraf, M., Rehman, S. U., Qamar, M. J., Zulqadar, S. A., & Mehdi, S. M. (2019). Combined impacts of compost, poultry manure and NPK fertilizers on yield of okra plant (*Abelmoschus esculentus* L.). *Pakistan Journal of Agricultural Research*, 32(3), 456-465.
- Acharya, N., Vista, S. P., Pandit, N. R., Bhattarai, S., & Dahal, B. (2024). Effect of four different types of vermicomposts on okra productivity and farm income. *Heliyon*, 10, Article e34351. <https://doi.org/10.1016/j.heliyon.2024.e34351>
- Adekiya, A. O., Agbede, T. M., Aboyeji, C. M., Dunsin, O., & Ugbe, J. O. (2019). Green manures and NPK fertilizer effects on soil properties, growth, yield, mineral and vitamin C composition of okra (*Abelmoschus esculentus* (L.) Moench). *Journal of the Saudi Society of Agricultural Sciences*, 18(2), 218-223. <https://doi.org/10.1016/j.jssas.2017.05.005>
- Adewole, M. B., & Ilesanmi, A. O. (2011). Effects of soil amendments on the nutritional quality of okra (*Abelmoschus esculentus* [L.] Moench). *Journal of Soil Science and Plant Nutrition*, 11, 45-55.
- Akter, M., Shil, N. C., & Ahmad, S. (2020). Effects of tillage and nutrient management on yield of okra (*Abelmoschus esculentus* (L.) Moench). *Thai Journal of Agricultural Science*, 53, 97-108.
- Asadu, C. O., Ezema, C. A., Ekwueme, B. N., Onu, C. E., Onoh, I. M., Adejoh, T., Ezeorba, T. P. C., Ogbonna, C. C., Otuh, P. I., Okoye, J. O., & Emmanuel, U. O. (2024). Enhanced efficiency fertilizers: Overview of production methods, materials used, nutrients release mechanisms, benefits and considerations. *Environmental Pollution and Management*, 1, 32-48. <https://doi.org/10.1016/j.epm.2024.07.002>
- Benchasri, S., Suwannasin, W., Domyos, S., & Domyos, P. (2021). Influence of fertilizer types on growth and yield in okra (*Abelmoschus esculentus* (L.) Moench) in southern, Thailand. *Journal of Vocational Education in Agriculture*, 5(2), 59-69.
- Billah, M., Khan, M., Bano, A., Nisa, S., Hussain, A., Dawar, K. M., Munir, A., & Khan, N. (2020). Rock phosphate-enriched compost in combination with rhizobacteria; A cost-effective source for better soil health and wheat (*Triticum aestivum*) productivity. *Agronomy*, 10, Article 1390. <https://doi.org/10.3390/agronomy10091390>
- Cahyani, V. R., Rahayu, Lakshitarsari, K. P., Megow, R. A. Z. W., & Azzahra, N. Y. (2024). Composting of rice straw-based materials using aerobic bioactivator isolated from rice straw, mahogany bark and cassava peels. *Caraka Tani: Journal of Sustainable Agriculture*, 39(1), 48-64.
- Dada, V. A., & Adejumo, S. A. (2015). Growth and yield of okra (*Abelmoschus esculentus* Moench) as influenced by compost application under different light intensities. *Notulae Scientia Biologicae*, 7(2), 217-226. <https://doi.org/10.15835/nsb.7.2.9437>
- Department of Agriculture. (2005). *Announcement of the Department of Agriculture subject: organic fertilizers standard, 2005*. <https://www.ratchakitcha.soc.go.th/DATA/PDF/2548/00172707.PDF>
- Department of Agriculture. (2022). *Evaluation of soil properties in the okra cultivation area*. Soil Science Research Group, Agricultural Production Sciences Research and Development Division, Department of Agriculture, Bangkok.
- Department of Agricultural Extension. (2025, January 15). *Okra*. <https://esc.doae.go.th/wp-content/uploads/2018/11/OKRA.pdf>

- Elkhalifa, A. E. O., Alshammari, E., Adnan, M., Alcantara, J. C., Awadelkareem, A. M., Eltoum, N. E., Mehmood, K., Panda, B. P., & Ashraf, S. A. (2021). Okra (*Abelmoschus Esculentus*) as a potential dietary medicine with nutraceutical importance for sustainable health applications. *Molecules*, 26, Article 696. <https://doi.org/10.3390/molecules26030696>
- Faassen, H. G. & Dijk, H. V. (1987). Manure as a source of nitrogen and phosphorus in soils. In H. G. van der Meer, R. J. Unwin, T. A. van Dijk & G.C. Ennik (Eds.). *Animal manure on grassland and fodder crops. Fertilizer or waste? Vol 30* (pp. 27-46). Springer.
- Farrag, H. M., & Bakr, A. A. (2023). Effect of applying bio-enriched rock phosphate on soil properties and wheat plant growth. *Egyptian Journal of Soil Science*, 63(1), 1-13. <https://doi.org/10.21608/EJSS.2022.162019.1535>
- Fernandes, R. B. A., Junior, I. A. D. C., Junior, E. S. R., & Mendonça, E. D. S. (2015). Comparison of different methods for the determination of total organic carbon and humic substances in Brazilian soils. *Revista Ceres*, 62(5), 496-501. <https://doi.org/10.1590/0034-737X201562050011>
- Gajbhiye, M., Patil, S., Awate, S., Kokare, S., Terdale, S., & Dubey, M. K. (2025). Valorization of rice stubble through biodegradation using hydrolytic enzyme-producing *Olivibacter oleidegradans* CMB10 and *Agrobacterium pusense* SFMB9. *Heliyon*, 11, Article e42094. <https://doi.org/10.1016/j.heliyon.2025.e42094>
- Grigatti, M., Ciavatta, C., & Marzadori, C. (2024). The fate of soil organic carbon from compost: A pot test study using labile carbon and ¹³c natural abundance. *Journal of Soil Science and Plant Nutrition*, 24, 2589-2598. <https://doi.org/10.1007/s42729-024-01680-6>
- Hazra, K. K., Ghosh, P. K., Venkatesh, M. S., Nath, C. P., Kumar, N., Singh, M. S. J., & Nadarajan, N. (2018). Improving soil organic carbon pools through inclusion of summer mungbean in cereal-cereal cropping systems in Indo-Gangetic plain, *Archives of Agronomy and Soil Science*, 64(12), 1690-1704. <https://doi.org/10.1080/03650340.2018.1451638>
- Helmke, P. A., & Sparks, D. L. (1996). Lithium, sodium, potassium, rubidium, and cesium. In D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston & M. E. Sumner (Eds.). *Methods of soil analysis part 3: Chemical methods* (pp. 551-574). Soil Science Society of America, Inc.
- Ho, T. T. K., Tra, V. T., Le, T. H., Nguyen, N. K. Q., Tran, C. S., Nguyen, P. T., Vo, T. D. H., Thai, V. N., & Bui, X. T. (2022). Compost to improve sustainable soil cultivation and crop productivity. *Case Studies in Chemical and Environmental Engineering*, 6, Article 100211. <https://doi.org/10.1016/j.cscee.2022.100211>
- Hossain, M. F., & Islam, M. S. (2024): Effects of organic and inorganic fertilizers and their combination on growth, yield and quality of broccoli (*Brassica oleracea* L. var. 'Italica'). *International Journal of Horticultural Science and Technology*, 11(4), 515-522. <https://doi.org/10.22059/ijhst.2024.365279.697>
- Jackson, M. L. (1965). *Soil chemical analysis*. Prentice Hall, Inc.
- Johnson, C. M., & Ulrich, A. (1959). Analytical methods for use in plant analysis. *Bulletin* 766, 25-78.
- Kuo, S. (1996): Phosphorus. In D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston & M.E. Sumner (Eds.). *Methods of soil analysis part 3: Chemical methods* (pp. 869-919). Soil Science Society of America, Inc.
- Land Development Department. (2020, November 16). *Manual of plant, fertilizer and soil conditioners analysis*. <https://www.idd.go.th/PMQA/2553/Manual/OSD-07.pdf>

- Land Classification Division and FAO Project Staff. (1973). *Soil Interpretation handbook for Thailand*. Land Development Department, Ministry of Agriculture and Cooperatives.
- Luan, H. A., Yuan, S., Gao, W., Tang, J. W., Li, R. N., Zhang, H. Z., & Huang, S. W. (2021). Changes in organic C stability within soil aggregates under different fertilization patterns in a greenhouse vegetable field. *Journal of Integrative Agriculture*, 20(10), 2758-2771. [https://doi.org/10.1016/S2095-3119\(21\)63646-8](https://doi.org/10.1016/S2095-3119(21)63646-8)
- Mahmood, F., Khan, I., Ashraf, U., Shahzad, T., Hussain, S., Shahid, M., Abid, M., & Ullah, S. (2017). Effects of organic and inorganic manures on maize and their residual impact on soil physico-chemical properties. *Journal of Soil Science and Plant Nutrition*, 17(1), 22-32. <https://doi.org/10.4067/S0718-95162017005000002>
- Moharana, P. C., Biswas, D. R., Ghosh, A., Sarkar, A., Bhattacharyya, R., & Meena, M. D. (2020). Effects of crop residues composts on the fractions and forms of organic carbon and nitrogen in subtropical Indian conditions. *Soil Research*, 58(1), 95-108. <https://doi.org/10.1071/SR19091>
- Mulvaney, R. L. (1996). Nitrogen-inorganic forms. In D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston & M. E. Sumner (Eds). *Methods of soil analysis part 3: Chemical methods* (pp. 1123-1184). Soil Science Society of America, Inc.
- Murphy, J., & Riley, J. P. (1962). A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta*, 27, 31-36. [https://doi.org/10.1016/S0003-2670\(00\)88444-5](https://doi.org/10.1016/S0003-2670(00)88444-5)
- Nandan, R., Singha, V., Singh, S. S., Kumar, V., Hazra, K. K., Nath, C. P., Poonia, S., Malik, R. K., Bhattacharyya, R., & McDonal, A. (2019). Impact of conservation tillage in rice-based cropping systems on soil aggregation, carbon pools and nutrients. *Geoderma*, 340, 104-114. <https://doi.org/10.1016/j.geoderma.2019.01.001>
- Nelson, D. W., & Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. In D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston & M. E. Sumner (Eds.). *Methods of soil analysis part 3: Chemical methods* (pp. 961-1010). Soil Science Society of America, Inc.
- Nghi, N. T., Romasanta, R. R., Hieu, N. V., Vinh, L. Q., Du, N. X., Ngan, N. V. C., Chivenge, P., & Hung, N. V. (2020). Rice straw-based composting. In M. Gummert, N. V. Hung, P. Chivenge & B. Douthwaite (Eds). *Sustainable Rice Straw Management* (pp. 33-41). SpringerOpen.
- Nguyen, T. T., Sasaki, Y., Nasukawa, H., & Katahira, M. (2024). Recycling potassium from cow manure compost can replace potassium fertilizers in paddy rice production systems. *Science of The Total Environment*, 912, Article 168823. <https://doi.org/10.1016/j.scitotenv.2023.168823>
- Rann, V., Anusontpornperm, S., Thanachit, S., & Sreewongchai, T. (2016). Response of KDML105 and RD41 rice varieties grown on a Typic Natrustalf to granulated pig manure and chemical fertilizers. *Agriculture and Natural Resources*, 50(2), 104-113. <https://doi.org/10.1016/j.anres.2015.12.001>
- Rice Department. (2025). *Weekly rice situation reports in Thailand*. https://files.ricethailand.go.th/files/2/documents/page_doc/files-rice-173805054824_4.pdf
- Rhoades, J. D. (1996). Salinity: electrical conductivity and total dissolved solids. In D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston & M. E. Sumner (Eds). *Methods of Soil Analysis Part 3: Chemical Methods* (pp. 417-435). Soil Science Society of America, Inc.
- Sinkumkoon, P., Thanachit, S., Anusontpornperm, S., Kheoruenromne, I., Petprapai, P., & Bowichean, R. (2015). Influences of green manures and N-fertilizer management on

- nutrient uptakes and yield of cassava on a degraded sandy soil. *Kasetsart Journal (Natural Science)*, 49, 375-389.
- Sukyankij, S., Sukyankij, S., & Panich-pat, T. (2023). Effect of co-fertilizer application and dolomite amendments on yield and grain quality of rice grown on post-active acid sulfate soil. *AGRIVITA Journal of Agricultural Science*, 45(2), 311-321. <https://doi.org/10.17503/agrivita.v45i2.4079>
- Sukyankij, S., Sukyankij, S., Khongsud, C., & Panich-pat, T. (2024). Effect of lime application on phosphorus adsorption and desorption in post-active acid sulfate soil, Thailand. *Journal of Degraded and Mining Lands Management*, 11(2), 5279-5286. <https://doi.org/10.15243/jdmlm.2024.112.5279>
- Sukyankij, S., Khongsud, C., Phun-lam, M., & Panich-Pat, T. (2025). Influence of silicon application on phosphorus uptake in rice and phosphorus availability in acid and neutral soils, Central Thailand. *International Journal of Agriculture and Biology*, 33 Article 330415. <https://doi.org/10.17957/IJAB/15.2305>
- Surin, P., Supsuan, P., & Yampracha, S. (2019). Release of various elements from organic fertilizers incubated in organic and non-organic paddy soils at various time periods. *Current Applied Science and Technology*, 19(3), 276-288.
- Thomas, G. W. (1996): Soil pH and soil acidity. In D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnston & M. E. Sumner (Eds). *Methods of Soil Analysis Part 3: Chemical Methods* (pp. 475-490). Soil Science Society of America, Inc.
- Westerman, R. L. (1990). *Soil Testing and Plant Analysis*. Soil Science Society of America, Inc.
- Widowati, Sutoyo, Karamina, H., & Fikrinda, W. (2020). Biochar and organic fertilizer utilization in enhancing corn yield on various types of dryland. *Agriculture and Natural Resources*, 54, 665-672. <https://doi.org/10.34044/j.anres.2020.54.6.13>
- Wu, Q., Zhang, S., Zhu, P., Huang, S., Wang, B., Zhao, L., & Xu, M. (2017). Characterizing differences in the phosphorus activation coefficient of three typical cropland soils and the influencing factors under long-term fertilization. *PLoS One*, 12, Article e0176437. <https://doi.org/10.1371/journal.pone.0176437>
- Yang, X., Chen, X., & Yang, X. (2019). Effect of organic matter on phosphorus adsorption and desorption in a black soil from Northeast China. *Soil and Tillage Research*, 187, 85-91. <https://doi.org/10.1016/j.still.2018.11.016>
- Zayed, G., & Abdel-Motaal, H. (2025). Bio-active composts from rice straw enriched with rock phosphate and their effect on the phosphorous nutrition and microbial community in rhizosphere of cowpea. *Bioresource Technology*, 96, 929-935. <https://doi.org/10.1016/j.biortech.2004.08.002>
- Zhang, L., & Sun, X. (2017). Addition of fish pond sediment and rock phosphate enhances the composting of green waste. *Bioresource Technology*, 233, 116-126. <https://doi.org/10.1016/j.biortech.2017.02.073>