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Effects of different organic fertilizers on residual nutrients, rice growth and yield

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Abstract Different organic fertilizers has affteted on the residual nutrients for rice growth and yield in the next cropping. Effects of different organic fertilizers on residual nutrients, rice growth and yield were studied. Results indicated that application of cow manure in the previous crop resulted in significant difference in exchangeable potassium (K). Other essential nutrients in soil after application of cow manure and compost residue were at high levels and sufficient for rice growth except for nitrogen (N). Residual cow manure with and without split application gave significantly highest rice tiller number and grain fresh and dry weight compared to the other treatments. Nitrogen uptake in grain and K uptake in straw from the cow manure residue was significantly different from the composted residue. Phosphorus (P) uptake in straw and grain yield of all treatments was not significantly different, relating to high amounts of soil available P. Total zinc (Zn) uptake from residual cow manure soil was also highest. Soil pH after harvesting decreased slightly and total and available P in the control (no organic fertilizer application) were lower than residual organic fertilizer treatments. Exchangeable K and extractable sodium (Na) of residual cow manure were highest in soil after harvesting. Residual cow manure gave high level of K which increased rice growth and yield but also increased accumulation of non-essential elements such as sodium (Na). Results suggested that organic fertilizers produced higher residual nutrients, except N, which were sufficient for rice growth and yield in the next cropping. Residual cow manure gave higher exchangeable K which had a positive effect on rice growth but increased Na accumulation in the soil.

Keywords: Sodium, Residual effect, Compost, Cow manure

Introduction

Application of organic fertilizer as a basal dressing can supply all essential elements for rice plant growth due to slow release during the decomposition of organic materials (Haynes and Naidu, 1998; Singh, 2012). Organic fertilizers have low nitrogen content so high application rates are required to satisfy the nutrient requirements of rice and to supplement the low

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available nitrogen content in the soil. However, accumulation of some essential and non-essential plant nutrients in the soil is unavoidable (Kokoasse and Desmond, 2016). Continuous applications of organic fertilizers cause some elements to accumulate in the soil. Rates of accumulation differ depending on organic fertilizers used and soil types (Song *et al*., 2017). Surin *et al*. (2019) reported that incubation of cow manure in non-organic paddy soil released higher available phosphorus (P), exchangeable potassium (K), and extractable sodium (Na) than incubation with organic paddy soil. High accumulation of some essential nutrients such as P, K and calcium (Ca) induce plant nutrient imbalance and risk to the environment, while accumulation of some non-essential plant elements such as Na can retard plant growth with also risk to the environment. Effective management of residual plant essential nutrients can reduce fertilizer cost for the next crop; however, in Thailand, there is scant information on this subject.

Nitrogen (N) is essential for rice growth and can be easily lost in paddy soil by yield harvesting, denitrification, volatilization, runoff, and leaching (Thawinthung, 2016). A split nitrogen fertilizer application can increase available nitrogen to adequate levels for rice growth. Supsuan *et al*. (2019) reported that split applications of cow manure and compost at different growing stages increased yield and nitrogen uptake, with no significant differences in nutrient accumulation. By contrast, Harold *et al*. (2006) found that the timing of cow manure, compost, and green manure applications enhanced nitrogen leaching. Nitrogen in organic fertilizers can be lost in liquid manure form and affected by cropping system and timing of application. Cow manure application resulting in increased soil phosphorus can be easily lost in paddy soil by runoff and transport into water resources, thereby promoting eutrophication phenomena (Pibumrung, 2015; Yan *et al*., 2017: Xin *et al*., 2017). Moreover, cow manure application increases soluble and exchangeable forms of K with higher release of soluble K than exchangeable K (Cees and Wim, 2009).

This study aimed to determine the effects of organic fertilizer application on residual nutrients, rice growth and yield in the subsequent rice cropping to increase understanding for improving management of residual nutrients from organic fertilizers. Here, the effects of different organic fertilizers on residual nutrients in the soil and rice growth and yield for the subsequent cropping were examined and discussed.

Materials and Methods

The soil used in this study was non-organic paddy soil which was applied with organic fertilizers at different rice growing stages following Supsuan (2018) who cultivated Pathumthani 1 rice variety from February to

June, 2018 in a greenhouse at the Faculty of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang. The non-organic paddy soil was collected from Nongchok District, Bangkok, Thailand which was classified as very-fine, smectitic, nonacid, isohyperthermic vertic endoaquepts Bangkok soil series.

Before rice cultivation, each soil sample was collected at 0-15 cm depth, air-dried and passed through a 2-mm sieve before soil properties analyses. Experiments were conducted using randomized complete block design (RCBD) with three replications. Seven treatments consisted of 1) soil without organic fertilizer application (control), 2) soil with compost residue without split application (CP1), 3) soil with compost residue with two split applications (CP2), 4) soil with cow manure residue without split application (CM1), 5) soil with cow manure residue with two split applications (CM2), 6) soil with compost and cow manure residue (CP1+CM1), and 7) soil with compost and cow manure residue with two split applications (CP1+CM2). Split applications of organic fertilizers in treatments 2-7 were performed following Supsuan (2018). All treatments were not applied with organic fertilizers.

Twenty-day-old rice seedlings (RD43 variety) were transplanted after flooding the soil with water at 10-15 cm depth above soil surface for 14 days before transplanting. Rice was transplanted on 15 August 2018 and harvested on 6 November 2018. Nitrogen and potassium were applied 7 days after transplanting as basal fertilizer and half nitrogen fertilizer was applied 45 days after transplanting at the rate of 39 kg N/rai and 20 kg K_2O/rai. Plant height, tiller number and chlorophyll content were recorded every week after transplanting until harvesting at 103 days. Chlorophyll content was measured on the three fully expanded uppermost leaves using a chlorophyll meter (SPAD502) (Yuan *et al*., 2016). Panicle number and straw and grain fresh and dry weights were recorded at the harvesting period. Soil samples in each treatment were collected after rice harvesting at 0-15 cm depth for residual nutrient analysis.

Soil pH was determined at a 1:1 ratio of soil and deionized water. Electrical conductivity (EC) was determined at a 1:5 ratio of soil and deionized water. Soil pH and electrical conductivity were measured using a pH meter and an EC meter (Richards, 1954). Organic matter was analyzed by loss on ignition method (Buchanan, 1984). Total N was determined using dry combustion (LECO Corporation, 2016). Total P and K were digested with nitric acid (HNO_3): perchloric acid ($HClO_4$) at 2:1 ratio. Concentrations of total P and K were measured using a coupled plasma optical emission spectrometer (ICP-OES) (Yampracha, 2013). Available P was extracted using Bray II, measured by the molybdenum blue method and determined using a spectrophotometer at wavelength 882 nm (Bray and Kurtz, 1945). Exchangeable K, Ca, Mg and extractable Na were extracted using the ammonium acetate method (Soil Chemical Research Center, 2001). Extractable iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) were extracted using the DTPA method (Lindsay and Norvell, 1978). Exchangeable cations and micronutrients were measured by a coupled plasma optical emission spectrometer (ICP-OES). Total N of straw and grain yield was measured using the Kjeldahl method (Soil Chemical Research Center, 2001). Total P, K and Zn of straw and grain yield were digested following the dry ashing method. Nutrient concentrations were measured using a coupled plasma optical emission spectrometer (ICP-OES) (Yampracha, 2013). Nutrient uptake was calculated as the percentage nutrient concentration of grain/straw x dry weight of grain/straw (kg/ha) divided by 100 (Kabir *et al.*, 2011).

All data were analyzed using analysis of variance (ANOVA) employing a statistical software package. Mean comparison was analyzed using Duncan's multiple range test (DMRT) at a significance level of 95%.

Results

Soil residual nutrients before rice cultivation

The soil chemical properties in all treatments before rice cultivation were not statistically different, except for exchangeable K (Table 1 and 2). The Soil pH in all treatments was neutral, which was suitable for rice growth. The electrical conductivity (EC) in all treatments did not exceed the safety level for rice growth (<2 mS/cm). The organic matter (OM) and total N in all treatments were at low level and not significantly different. The total amount of P and K were high in all treatments, while available P of organic fertilizer residue was higher than the critical value for rice growth. The exchangeable K, Ca, Mg and extractable Na were high in all treatments. The exchangeable K was highest in CM1 and significantly different from the other treatments. The extractable Fe, Mn, Zn and Cu in all treatments were not statistically different (Table 2).

Rice growth

Results showed that plant height of rice in all treatments at the initial growth stage was not significantly different. Initial rice height at 7 days after transplanting was between 34.7 and 42.1 cm. Rice height in all treatments increased rapidly from 7 to 49 days after transplanting and then maintained a steady state from 56 to 70 days. At 70 days after transplanting, rice height of all treatment was not significantly different with values between 116.5 and 130.2 cm (Figure 1).

Table 1. Soil pH, electrical conductivity (EC), organic matter (OM), total N (TN), total P (TP), total K (TK) and available P before rice cultivation.

Treatment	$pH_{(1:1)}$	$EC_{(1:5)}$ (mS/cm)	OM (g/kg)	TN (g/kg)	TP (g/kg)	TK (g/kg)	Available P (mg/kg)
Control	7.08	0.10	40.95	2.10	0.25	5.52	41.70
CP1	7.12	0.07	40.66	2.07	0.24	6.27	42.43
CP2	7.23	0.08	41.38	2.06	0.29	6.30	45.97
CM1	7.13	0.12	40.29	1.99	0.20	5.10	48.93
CM2	6.96	0.14	40.12	1.97	0.25	6.10	44.23
CP1+CM1	7.01	0.15	43.83	2.19	0.27	5.90	47.70
CP1+CM2	6.99	0.14	41.91	2.13	0.20	5.01	45.97
F-test	ns	ns	ns	ns	ns	ns	ns
CV (%)	1.89	34.40	4.90	7.40	31.21	15.29	16.11

ns = not significantly differenced at $p \leq 0.05$.

Table 2. Exchangeable K, Ca, and Mg, extractable Na, Fe, Mn, Zn and Cu before rice cultivation

Treatment	Exchangeable (mg/kg)			Extractable (mg/kg)				
	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
Control	66.90b	2,841.29	610.95	232.67	348.76	25.02	0.62	1.59
CP1	64.42b	3,462.10	539.78	200.05	348.70	27.20	0.63	1.46
CP2	64.15b	3,201.43	571.98	206.30	353.79	25.55	0.50	1.45
CM1	119.36a	3,118.61	592.29	265.37	340.26	29.47	0.62	1.88
CM2	90.60b	3,013.39	598.69	246.25	351.58	30.81	1.21	1.89
CP1+CM1	84.31b	3,591.68	589.13	254.93	348.79	27.24	2.75	1.49
CP1+CM2	78.62b	3,205.77	568.16	236.29	346.54	34.67	2.39	2.21
F-test	**	ns	ns	ns	ns	ns	ns	ns
CV (%)	14.66	8.20	7.40	16.20	3.60	26.00	41.77	21.90

** = significantly differenced at $p \leq 0.01$, ns = not significantly differenced at $p \leq 0.05$.

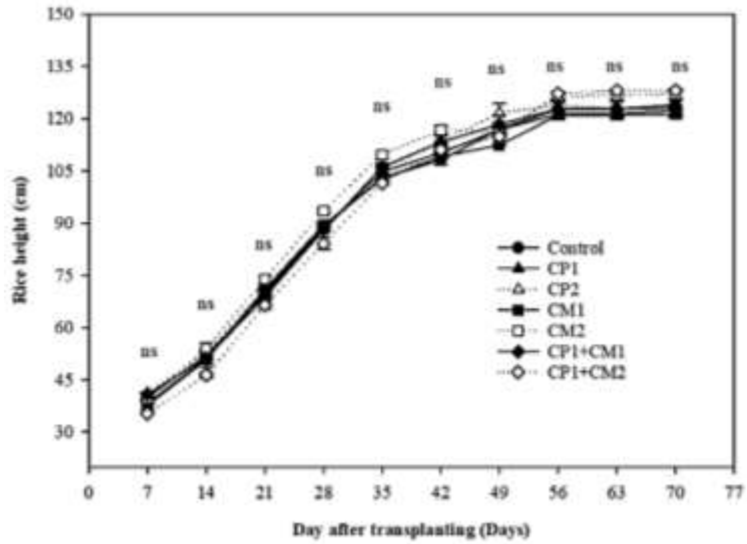

Figure 1. Height of rice in days after transplanting during cultivation. Error bar = Standard error of mean (SE), ns = not significantly differenced at $p \leq 0.05$

The tiller number in all treatments increased regularly, with no significant difference at 7-28 days after transplanting. At 35 to 70 days after transplanting, CM1 and CM2 had the highest tiller number followed by CP2 and CP1+CM1, respectively (Figure 2).

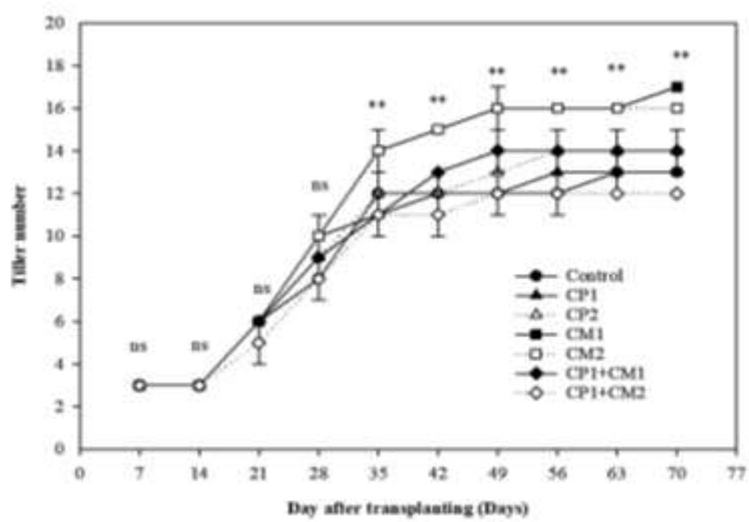

Figure 2. Tiller number of rice in days after transplanting during cultivation. Error bar = Standard error of mean (SE), ** = significant difference at $p \leq 0.01$, ns = not significantly differenced at $p \leq 0.05$

The initial Soil Plant Analysis Development (SPAD) of rice leaves in all treatments was not significantly different. The initial SPAD at 7 days after transplanting was between 26.6 and 29.8 cm. The SPAD values in all treatments increased gradually from 7 to 35 days after transplanting and decreased at 42 days after transplanting. The SPAD values in CP1+CM2 were highest at 56, 63 and 70 days after transplanting and were significantly different from the other treatments (Figure 3).

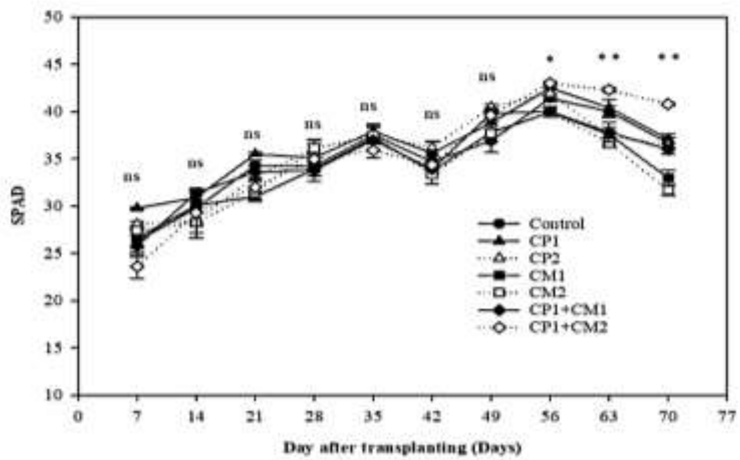

Figure 3. SPAD of rice leaves in days after transplanting during cultivation. Error bar = Standard error of mean (SE), * = significant difference at $p \leq 0.05$, ** = significant difference at $p \leq 0.01$, ns = not significantly differenced at $p \leq 0.05$

Rice yield component, yield and nutrient uptake

Results showed that panicle number as well as fresh and dry weights of straw in all treatments were not significantly different. Fresh and dry weights of grain were highest in CM1 and CM2 and statistically different from the other treatments at 0.01 significance level (Table 3).

Uptake N in grain was highest in CM2 and significantly different from the control but not significantly different from CM1 and CP2. Uptake N in straw and total N uptake were not significantly different and similar to uptake P in straw, grain and total P uptake (Table 4).

Results showed that potassium uptake of straw and total potassium uptake were highest and significantly different in CM1 and CM2, followed by CP1+CM1 and CP1+CM2, respectively. Total zinc uptake was highest in CM1 and CM2 and significantly different from the other treatments. By contrast, uptake of potassium in grain was not significantly different and similar to uptake of zinc in straw and grain (Table 5). The uptake of other essential plant nutrients such as Ca, Mg, Fe, Mn and Cu were not significantly different (data not shown).

Table 3. The panicle number, fresh and dry weight of straw and grain

Treatment	Panicle number (panicles/pot)	Straw		Grain	
		Fresh weight (g/pot)	Dry weight (g/pot)	Fresh weight (g/pot)	Dry weight (g/pot)
Control	15	104.51	31.48	35.88b	24.89b
CP1	17	108.64	31.86	40.65b	27.48b
CP2	16	110.01	30.96	38.23b	26.24b
CM1	17	109.98	32.85	52.07a	35.66a
CM2	16	111.59	32.43	52.56a	35.03a
CP1+CM1	15	114.02	33.01	38.84b	27.22b
CP1+CM2	15	110.37	32.27	38.59b	26.68b
F-test	ns	ns	ns	**	**
CV (%)	14.97	10.52	9.83	6.78	7.34

** = significantly differenced at $p \leq 0.01$, ns = not significantly differenced at $p \leq 0.05$.

Table 4. Uptake nitrogen (N) and phosphorus (P) in rice straw and grain

Treatment	Uptake N (g/pot)			Uptake P (g/pot)		
	Straw	Grain	Total	Straw	Grain	Total
Control	0.27	0.40c	0.67	0.07	0.08	0.15
CP1	0.30	0.43bc	0.73	0.08	0.09	0.16
CP2	0.28	0.44abc	0.72	0.08	0.09	0.17
CM1	0.22	0.50ab	0.72	0.06	0.11	0.17
CM2	0.23	0.51a	0.74	0.05	0.11	0.17
CP1+CM1	0.29	0.43bc	0.71	0.07	0.09	0.16
CP1+CM2	0.29	0.43bc	0.72	0.07	0.09	0.16
F-test	ns	*	ns	ns	ns	ns
CV (%)	16.58	8.97	4.09	15.60	7.47	5.78

* = significantly differenced at $p \leq 0.05$, ns = not significantly differenced at $p \leq 0.05$.

Table 5. Uptake potassium (K) and zinc (Zn) in rice straw and grain

Treatment	Uptake K (g/pot)			Uptake Zn (mg/pot)		
	Straw	Grain	Total	Straw	Grain	Total
Control	0.40b	0.08	0.49bc	0.63	0.73	1.35bc
CP1	0.28c	0.09	0.36c	0.47	0.78	1.25c
CP2	0.27c	0.10	0.37bc	0.48	0.80	1.28c
CM1	0.61a	0.13	0.74a	0.63	1.05	1.68a
CM2	0.59a	0.13	0.73a	0.62	0.97	1.59ab
CP1+CM1	0.35b	0.10	0.44bc	0.49	0.81	1.30c
CP1+CM2	0.41bc	0.09	0.50b	0.52	0.81	1.33c
F-test	**	ns	**	ns	ns	**
CV (%)	15.98	6.94	13.45	19.43	11.21	9.90

** = significantly differenced at $p \leq 0.01$, ns = not significantly differenced at $p \leq 0.05$.

Soil residual nutrients after rice cultivation

Soil pH after rice cultivation in all treatments became slightly acidic with no statistical differences but slightly decreased from soil pH before cultivation. Electrical conductivity in all treatments was not above toxicity levels for rice. Soil organic matter, total N, and total K content in all treatments were not statistically different but slightly decreased compared with that before cultivation. Total P content after harvesting in all soils with residue organic fertilizers was statistically different but higher than the control (Table 6). Available P was highest in CM1 followed by CM2, while available P of organic fertilizer residual was higher than the critical value for rice growth (Pibumrung, 2015). Exchangeable K was highest in CM2 and CM1, and significantly different from other treatments. Exchangeable Ca, Mg and extractable Na were highest in CM2 followed by CM1. Extractable Fe, Mn, Zn and Cu of all treatments were not statistically different (Table 7).

Table 6. Soil pH, electrical conductivity (EC), organic matter (OM), total N (TN), total P (TP), total K (TK) and available P after rice cultivation

Treatment	$pH_{(1:1)}$	$EC_{(1:5)}$ (mS/cm)	OM (g/kg)	TN (g/kg)	TP (g/kg)	TK (g/kg)	Available P (mg/kg)
Control	6.41	0.52	41.21	2.06	0.21b	4.50	38.59d
CP1	6.30	0.58	41.60	2.08	0.24a	4.50	44.33cb
CP2	6.32	0.57	40.89	2.04	0.25a	4.73	42.40c
CM1	6.18	0.65	42.00	2.10	0.27a	4.80	48.71a
CM2	6.43	0.65	41.78	2.09	0.26a	4.37	46.68ab
CP1+CM1	6.34	0.65	42.07	2.10	0.25a	4.27	45.40bc
CP1+CM2	6.40	0.59	42.88	2.14	0.26a	4.54	45.42bc
F-test	ns	ns	ns	ns	*	ns	**
CV (%)	2.70	11.00	6.12	6.12	7.59	19.87	3.81

* = significantly differenced at $p \leq 0.05$, ** = significantly differenced at $p \leq 0.01$, ns = not significantly differenced at $p \leq 0.05$.

Table 7. Exchangeable K Ca and Mg, extractable Na, Fe, Mn, Zn and Cu after rice cultivation

Treatment	Exchangeable (mg/kg)				Extractable (mg/kg)			
	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
Control	89.93b	2,716.57	607.28	372.65bc	233.27	35.10	6.52	5.39
CP1	75.94b	2,750.00	622.10	368.56bc	231.95	33.64	6.49	5.18
CP2	87.43b	2,778.24	626.19	376.69bc	231.22	34.70	6.90	5.10
CM1	125.28a	2,772.55	631.02	454.35ab	231.38	34.04	6.27	5.14
CM2	127.95a	2,741.80	648.18	485.56a	235.10	37.62	6.71	5.25
CP1+CM1	71.89b	2,302.30	539.38	360.29c	232.33	33.15	6.13	5.05
CP1+CM2	87.14b	2,749.33	629.33	411.61abc	233.33	34.17	6.81	5.09
F-test	**	ns	ns	*	ns	ns	ns	ns
CV (%)	12.92	10.06	10.24	11.38	2.20	6.60	12.20	2.70

* = significantly differenced at $p \leq 0.05$, ** = significantly differenced at $p \leq 0.01$, ns = not significantly differenced at $p \leq 0.05$.

After rice cultivation, the available P was similar to soil before cultivation, except for the control treatment where available P slightly decreased. Exchangeable Ca and Mg decreased due to rice uptake but exchangeable K and extractable Na increased compared with values before cultivation. The extractable Fe decreased after cultivation while extractable Mn, Zn, and Cu increased.

Discussion

Soil pH in all treatments was neutral and suitable for rice growth. Electrical conductivity (EC) in all treatments did not exceed the safety level for rice growth (<2 mS/cm) (Rice Department, 2017). Organic matter and total N of all treatments were at low levels and not significantly different. The total amount of P and K were at high levels in all treatments, possibly affected by organic fertilizer application in the previous experiment that caused high total P and K accumulation in soil. Available P of organic fertilizer residue was higher than the critical value for rice growth and could cause risk to the environment (Pibumrung, 2015). Exchangeable K, Ca, Mg and extractable Na were high in all treatments. Exchangeable K was highest in CM1 and significantly different from the other treatments, possibly due to the decomposition of total K to exchangeable K in cow manure. Extractable Fe, Mn, Zn and Cu of all treatments were not statistically different and suitable for rice growth.

Rice height in all treatments after transplanting was not significantly different. The same nitrogen rate was applied in all treatments, causing adequate nitrogen for rice growth (Rice Department, 2017). Tiller number in all treatments at 35 to 70 days after transplanting found that CM1 and CM2 had the highest tiller number, possibly because cow manure contains high potassium, causing high uptake of potassium in straw and grain. Potassium plays a key role in the physiological processes of plant growth and development (Chen *et al*., 2015).

The initial SPAD values in all treatments increased gradually from 7 to 35 days after transplanting. This show that nutrient content was adequate for rice growth (KAS, 2016). The SPAD value of all treatments decreased at 42 days after transplanting due to potassium deficiency. After potassium fertilizer application at 10 kg K_2O/rai at 45 days after transplanting, the SPAD value in all treatments increased at 49 days after transplanting. The SPAD value in all treatments decreased at 56, 63 and 70 days after transplanting because the RD43 is a late-harvesting variety (Rice Department, 2017).

Fresh and dry weights of grain were highest in CM1 and CM2 and significantly different at the 0.01 level, possibly due to uptake of N in grain.

Sinclair (1998) reported that rice plant nitrogen accumulation increased grain yield and plant harvest index.

N uptake of grain was highest in soil with cow manure residue application (CM2 and CM1), possibly due to mineralization of labile organic nitrogen (Zhang *et al*., 2012), while uptake of P in straw grain and total were not significantly different. Uptake of K in straw and the total (straw and grain) were highest in soil with cow manure residue (CM1 and CM2), possibly due to residual exchangeable K in the soil before rice cultivation at higher than other treatments. Total Zn uptake was highest in soil with cow manure residue (CM1 and CM2), possibly due to higher rice growth of CM1 and CM2 than the other treatments.

The soil pH in all treatments before planting was higher than after planting. Soil pH value after rice harvesting was slightly acidic, this caused the release of extractable Mn, Zn, and Cu for rice uptake. The electrical soil conductivity in all treatments before and after planting did not exceed the safety level for rice growth (<2 mS/cm). Electrical conductivity after planting was slightly higher than before planting, possibly due to application of nitrogen and potassium chemical fertilizer. The total P before planting was higher than after planting while available P after planting was higher than before planting. This indicated that the increase in available P resulted to the release of available P from total P (Pornkanung *et al*., 2018). Application of cow manure strongly affected the release of potassium probably due to high K content of cow manure (Supsuan *et al*., 2018; Surin *et al*., 2019). Extractable Fe of all treatment after planting was lower than before planting, possibly due to decrease of soil pH which induced ferrous iron precipitation with compounds in soil such as magnetite ($Fe_3O_4.nH_2O$), black hydrotroilite ($FeS.nH_2O$), white siderite ($FeCO_3$) and blue vivianite ($Fe_3PO_4.8H_2O$) in acidic condition (Kozlowski, 1984; Surin *et al*., 2018). The extractable Na in all treatments after planting was higher than before planting and residual cow manure showed significant difference from residue compost. Supsuan (2018) reported that the total Na in cow manure which was applied to the soil in this study was 1.98 g/kg and higher than compost (0.73 g/kg). The high amount of residual nutrients from cow manure was due to high mineralization rate of cow manure compared with less mineralization rate in compost (Eghball *et al*., 2002).

Conclusion

Our results conclude that residual organic fertilizers provide sufficient essential plant nutrients except N for rice growth and yield in the next cropping. However, exchangeable K from residual compost has negative impact on rice growth. Different types of organic fertilizer residues significantly affected soil residual nutrients, rice growth and yield. Residual cow manure with and without split application gave significantly higher tiller number and grain fresh and dry weight compared with the other treatments. Nitrogen uptake in grain and potassium uptake in straw from cow manure residue were significantly different from residues of compost. Phosphorus uptake in straw and grain yield of all treatments were not significantly different because of the high amount of available P. Residual effects of cow manure and compost diversely affected soil accumulation of available phosphorus, exchangeable potassium, and extractable sodium. Applying cow manure supply essential nutrients for next cropping. However, applying the same type of organic fertilizers, essentially cow manure induced the risk of salt accumulation. Therefore, applications of organic fertilizers such as green manure can improve soil nitrogen contents without non-essential nutrient accumulation.

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