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Original article

Response of KDML105 and RD41 rice varieties grown on a Typic Natrustalf to granulated pig manure and chemical fertilizers

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ABSTRACT

A study on the effect of composted pig manure and chemical fertilizers on the yield and plant nutrients uptake of the KDML105 and RD41 rice varieties grown on a Typic Natrustalf was carried out in a field of the Farmer Occupational Research and Development Centre, Ban Panead, Khok Samrong district, Lopburi province in 2013. The soil on the experimental area contained some soil constraints that adversely gave a low rice yield; therefore, the study investigated the response of two rice varieties to the application of composted pig manure and chemical fertilizers. A factorial, randomized, complete block design with three replications was employed. The first factor comprised the two rice varieties while the second factor consisted of six treatments consisting of no added fertilizer, sole and a combination of composted pig manure and chemical fertilizers. The results showed that both rice varieties produced similar amounts of grain yield—1.32 t/ha for the KDML105 variety and 1.28 t/ha for the RD41 variety. The KDML105 variety had greater vegetative growth than the RD41 variety. The application of 50% composted pig manure plus 100% chemical fertilizers highly significantly promoted the rice grain yield to the highest level achieved (1.88 t/ha), whereas the sole application of chemical fertilizer (T2) as commonly used by local farmers and 50% composted pig manure (T4) gave much lower yields, albeit greater than the control without manure added or fertilization. Almost all major and minor plant nutrients were statistically more concentrated in the grain of RD41 than in KDML105, while some micronutrients accumulated more in KDML105. In general, the application of 50% composted pig manure together with 100% chemical fertilizer (T5) effectively promoted the highest uptake of most plant nutrients in both the grain and straw, which coincided with the highest grain yield. While there were no statistically significant differences, RD41 with the addition of 50% composted pig manure together with 100% chemical fertilizer tended to give the highest grain yield of 2.29 t/ha when grown on this poor soil.

Introduction

Rice is the staple crop of Asia, where more than 90% of the world's rice is grown and consumed (Janoria, 1989) and is one of the top five major carbohydrate crops for the world's population, especially in Asia. It is a major staple food, supporting more than three billion people, comprising 50–80% of their daily calorie intake (Khush, 2005). In Thailand, rice is one of major economic crops mainly grown in the lowland areas in all regions of the country. The Khao Dawk Mali 105 (KDML105) variety, commonly known as jasmine rice, is a premium quality rice and very famous on the world market because of its unique, long, slender grain and white color. Moreover, it tastes soft and smells like a natural fragrance after cooking (Kongsri et al., 2002). The potential yield of this variety is 2.28 t/ha (Sri-aun, 2005; Bureau of Rice Research and Development, 2015a). There are many newly bred rice varieties in Thailand, with RD41 being one of them that is also deemed to be tolerant to a poor environment yet having a potential yield of 4.51 t/ha (Bureau of Rice Research and Development, 2015b) However, Thai paddy soils vary greatly, resulting in different amounts of rice yield. Thus, the average yield of rice in the country was reported to be only 2.33 t/ha (Global Rice Research Partnership, 2013). Sodic soil is one of the problem soils in Thailand, and it has been used mainly for growing paddy rice. The colloidal dispersion caused by

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sodicity may harm plants in at least two ways: 1) oxygen becomes deficient due to the breakdown of the soil structure and the very limited air movement that results, and 2) water relations are poor due largely to the very slow infiltration and percolation (Brady and Weil, 2008). The addition of salts to the soil alters its physical and chemical properties, including the soil structure and hydraulic conductivity. Excessive exchangeable sodium and high pH decrease the soil permeability and infiltration capacity through swelling and dispersion of clays as well as slaking of aggregates (Läuchli and Epstein, 1990; Rengasamy and Olsson, 1991; De Pascale et al., 2005). In addition, deterioration of the chemical, biological and biochemical properties of sodic soils has been well reported in the literature (McClung and Frankenberger, 1985; García and Hernández, 1996; Pathak and Rao, 1998; Rietz and Haynes, 2003; Ghollarata and Raiesi, 2007; Wong et al., 2008; Setia et al., 2012). Xu et al. (2008) reported that organic manure application with chemical fertilizers increased the yield and nitrogen use efficiency of rice, reduced the risk of environmental pollution and improved soil fertility greatly. The application of compost and plant residues can improve the soil structure and nutrient supply to the growing crop and thereby reduce the input requirement of mineral fertilizer (De Datta, 1981; Supprattanapan et al., 2009). Recycling animal manure and crop straw by incorporation into the soil can supply valuable quantities of plant nutrients and organic matter to meet crop nutrient requirements and maintain soil fertility (Satyanarayana et al., 2002; Yang et al., 2004). Recently, various organic amendments such as mulch, manures and composts, have been investigated for their effectiveness in soil remediation. It has been demonstrated that the application of organic matter to saline soils can accelerate Na^+ leaching, decrease the exchangeable sodium percentage and electrical conductivity and increase the water infiltration, water holding capacity and aggregate stability (El-Shakweer et al., 1998; Tejada et al., 2006). Furthermore, the application of organic matter increases the soil microbial biomass and some soil enzymatic activities such as urease, alkaline phosphatase and b-glucosidase (Blagodatsky and Richter, 1998; Liang et al., 2003; Tejada et al., 2006).

This study investigated the response of the KDML105 and RD41 rice varieties grown on a Typic Natrustalf to composted pig manure and chemical fertilizers. The rice grain yield, plant components, plant nutrients concentrations and uptake in the grain and straw were measured.

Materials and methods

Experimental site and soil properties prior to conducting the experiment

The field trial was carried out in a paddy field at the Farmer Occupational Research and Development Centre, Ban Panead, Khok Samrong district, Lopburi province (26°45′36″N and 111°52′12″E). The area is a tropical savanna with an average annual temperature of 28 °C and the average annual rainfall of 1097 mm. The experiment was set up on soil with the presence of a fragipan underneath (Phunmuang et al., 2011). The topsoil contained 719, 105 and 156 g/kg of sand, silt and clay, respectively, having a sandy loam textural class (Table 1). Soil pH (measured in 1:1 soil/water) was 4.8 (very strongly acid). The soil had low organic matter (5.5 g/kg), very low total nitrogen (0.3 g/kg), very low available phosphorus (0.88 mg/kg) and very low available potassium (16.6 mg/kg) contents. Other minor and micronutrients were found in small amounts while the cation exchange capacity was low, indicating that this soil had poor ability to retain plant nutrients.

Experimental design

Two rice varieties—KDML105 and RD41—were transplanted using 1-month and 3-week old seedlings, respectively, in early June and harvested in late November 2012. The transplanting density was 25 cm × 25 cm with one seedling per hill. A factorial, randomized, complete block design with three replications was employed. The first factor consisted of the two varieties of rice and the second factor comprised six treatments: T1, control (no application of manure and fertilizer); T2, 100% chemical fertilizer; T3, 100% composted pig manure; T4, 50% composted pig manure; T5, 50% composted pig manure + 100% chemical fertilizer; and T6, 50% composted pig manure + 50% chemical fertilizer. The composted pig manure (100%) was applied at 6.25 t/ha. The manure was available in the local market and was commonly used by farmers and contained 3.67% N, 4.24% P_2O_5 and 0.07% K_2O. The 100% chemical fertilizer consisted of chemical fertilizer grade 16–16–8 (N–P_2O_5–K_2O) and was applied at the rate of 125 kg/ha and urea was applied at the rate of 62.5 kg/ha. The former was applied at 10 d after transplanting and the urea was split into two equal applications (first half applied at 30 d after planting and the second half applied at the panicle initiation stage). The composted pig manure had a pH of 6.2, electrical conductivity (EC, determined using water saturated paste) of 16.1 dS/m, cation exchange capacity (CEC) of 41.9 $cmol_c$/kg, 162 g/kg of organic matter, 3.67% of nitrogen, and 4.24%, 0.07%, 4.46% and 1.66% of available phosphorus, potassium, calcium and magnesium, respectively, 11.4 g/kg of total sulfur and 2.74 mg/kg, 10.9 mg/kg, 0.63 mg/kg and 0.70 mg/kg of exchangeable iron, zinc, copper and manganese, respectively. The manure was applied and incorporated into the soil at 1 wk before transplanting. Each plot size was 3 m × 3 m and was separated by a soil bund (50 cm width and 50 cm height) to avoid any overflow of floodwater.

Sample collection and soil and plant analyses

Soil samples—topsoil (0–15 cm) and subsoil (>15–60 cm)—were collected prior to conducting the experiment. The soil samples were air-dried, gently crushed using an agate mortar and pestle, passed through a 2 mm sieve and stored in a plastic bag. However, the soil organic carbon and total nitrogen contents were passed through a 0.5 mm sieve. These samples were analyzed to determine chemical properties. The soil pH was determined in a 1:1 soil:water ratio using a glass electrode pH meter (Kellogg Soil Survey Laboratory, 2014). Organic carbon was determined using the method of Walkley and Black titration (Walkley and Black, 1934; Nelson and Sommers, 1996) and the value was converted to soil organic matter content by multiplying the percentage of carbon by 1.724. Total nitrogen was determined using the Kjedahl method (Bremner, 1996). Available phosphorus was determined using Bray II (Bray and Kurtz, 1945) and measured using spectrophotometry. Available potassium was analyzed using 1 M NH_4OAc at pH 7.0 extraction (Pratt, 1965) and measured using atomic absorption spectrophotometry. Extractable bases (calcium, magnesium, potassium and sodium) were extracted with neutral 1 M NH_4OAc (Thomas, 1996), measured using atomic absorption spectrophotometry and converted to available contents. The CEC determination followed the procedure of Chapman (1965) with the removal of exchangeable bases with 1 M NH_4OAc at pH 7 and subsequent replacement of exchange NH_4^+ ions with 10% NaCl, and distillation of NH_3 into 2% H_3BO_3 followed by titration with 0.01 M HCl using bromocresol green-methyl red indicator. Extractable sulfate was analyzed using the turbidimetric method (Reisenauer et al., 1973; Tabatabai, 1996) and measured using spectrophotometry. Extractable Fe, Mn, Cu and Zn were determined using

Table 1
Chemical properties of soil prior to conducting the experiment.

Property	Topsoil	Subsoil	Property	Topsoil	Subsoil
pH (1:1 soil/water)	4.80	5.50	Available Mg (mg/kg)	15.80	13.70
CEC[a] ($cmol_c$/kg)	5.13	6.13	Available Na (mg/kg)	45.30	240.90
Organic matter (g/kg)	5.50	2.92	Total S (mg/kg)	11.30	8.30
Total N (g/kg)	0.32	0.23	Exchangeable Fe (mg/kg)	76.60	38.90
Available P (mg/kg)	0.88	1.80	Exchangeable Zn (mg/kg)	0.14	0.74
Available K (mg/kg)	16.55	11.54	Exchangeable Cu (mg/kg)	0.06	0.12
Available Ca (mg/kg)	199.00	69.50	Exchangeable Mn (mg/kg)	2.21	0.54

[a] Cation exchange capacity.

0.005 M DTPA, 0.005 M $CaCl_2$ and 0.1 M TEA (triethanolamine) buffered at pH 7.3 (Viets and Lindsay, 1973) and measured using atomic absorption spectrophotometry. The EC was determined using the saturation extract method at 25 °C and measured with an electrical-conductivity bridge (United State Salinity Laboratory Staff, 1954).

Plant samples were chopped and dried in an oven at 65–70 °C until the samples had constant weight. Then, the samples were crushed and ground into pieces smaller than 0.5 mm in size. Rice grain and straw samples with the exclusion of the 5 cm of straw above the soil surface and the roots, were used for the determination of the nutrient concentration and then converted into nutrient uptake. Total nitrogen was extracted by digestion mixture (H_2SO_4–Na_2SO_4–Se) and determined using the Kjeldahl method (Jackson, 1965). Total phosphorus was extracted by digestion mixture (HNO_3–H_2SO_4–$HClO_4$; Johnson and Ulrich, 1959) and determined using the vanado-molybyellow color method (Westerman, 1990), and then measured using spectrophotometry with a 440 nm wavelength (Murphy and Riley, 1992). Total potassium (K), calcium (Ca), magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn) and copper (Cu) were analyzed using digestion acid mixture extraction (HNO_3–H_2SO_4–$HClO_4$; Johnson and Ulrich, 1959) and determined using atomic absorption spectrophotometry (Westerman, 1990). Total sulfur (S) was analyzed by digestion with acid mixture (HNO_3–$HClO_4$; Johnson and Ulrich, 1959) and determined turbidimetrically as $BaSO_4$, and the amount was determined using spectrophotometry with a 450 nm wavelength (Bardsley and Lancaster, 1965).

Table 2
Response of KDML105 and RD41 rice to organic and chemical fertilizers on yield and plant components.

Treatment	Grain yield (t/ha)	Straw weight (t/ha)	Rice plant height (cm)	Tiller number (per hill)	Panicle number (per hill)	Filled grain (per panicle)	Undeveloped Kernels (per panicle)	%Filled grain (%)	100 grain weight (g)
Rice variety									
KDML105	1.32	2.46^{a}	119.2^{a}	8.5^{b}	7.7^{b}	100.0^{a}	29.6^{a}	77.1	2.83^{b}
RD41	1.28	1.49^{b}	70.7^{b}	13.0^{a}	11.8^{a}	41.7^{b}	9.6^{b}	81.5	3.33^{a}
F-test	ns	**	**	**	**	**	**	ns	**
Fertilizer									
JT1	0.54^{c}	0.79^{c}	79.8^{c}	4.6^{d}	4.0^{d}	71.3	15.6	83.5	2.96
JT2	1.03^{bc}	1.54^{bc}	91.0^{b}	9.5^{c}	8.6^{c}	64.7	21.5	77.5	3.11
JT3	1.73^{a}	2.57^{a}	103.8^{a}	12.5^{ab}	11.8^{ab}	73.0	19.1	79.0	3.07
JT4	1.05^{bc}	1.60^{b}	92.0^{b}	10.4^{bc}	9.4^{bc}	66.3	20.0	78.0	3.03
JT5	1.88^{a}	2.72^{a}	102.0^{a}	14.9^{a}	13.5^{a}	74.4	25.4	76.5	3.13
JT6	1.57^{ab}	2.67^{a}	100.8^{a}	12.5^{ab}	11.3^{abc}	75.5	16.1	81.6	3.18
F-test	**	**	**	**	**	ns	ns	ns	ns
Interaction: variety × fertilizer									
JJT1	0.88	1.07	104.7	4.9^{fg}	4.1	112.7	26.0	81.2	2.73
JJT2	1.05	1.99	114.3	8.3^{efg}	7.2	94.7	35.3	72.9	2.92
JJT3	1.64	3.42	128.3	10.3^{cde}	9.5	99.3	25.7	79.8	2.83
JJT4	1.07	1.71	111.3	7.7^{efg}	6.8	92.0	30.7	74.4	2.73
JJT5	1.48	3.17	126.0	10.9^{cde}	10.1	94.3	38.7	70.8	2.83
JJT6	1.80	3.43	130.3	8.8^{def}	8.5	107.3	21.0	83.6	2.93
JRT1	0.21	0.52	55.0	4.3^{g}	4.0	30.0	5.1	85.7	3.18
JRT2	1.01	1.08	67.7	10.7^{cde}	10.1	34.7	7.7	82.1	3.30
JRT3	1.82	1.72	79.3	14.7^{abc}	14.0	46.7	12.5	78.2	3.30
JRT4	1.03	1.50	72.7	13.2^{bcd}	11.9	40.7	9.3	81.6	3.32
JRT5	2.29	2.26	78.0	18.8^{a}	17.0	54.5	12.2	82.1	3.43
JRT6	1.34	1.90	71.3	16.3^{ab}	14.0	43.7	11.2	79.6	3.43
F-test	ns	ns	ns	*	ns	ns	ns	ns	ns
%CV	35.0	31.9	6.3	22.1	23.0	22.2	50.2	10.1	4.4

ns = non-significant; *, ** significantly different at 0.05 and 0.01 probability levels, respectively; means with different superscript letters within a column indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.
T1 = no fertilization; T2 = chemical fertilizer (100%); T3 = pig manure (100%); T4 = pig manure (50%); T5 = pig manure (50%) + chemical fertilizer (100%); T6 = pig manure (50%) + chemical fertilizer (50%).
R = RD41 rice variety; J = jasmine rice (KDML105 variety).

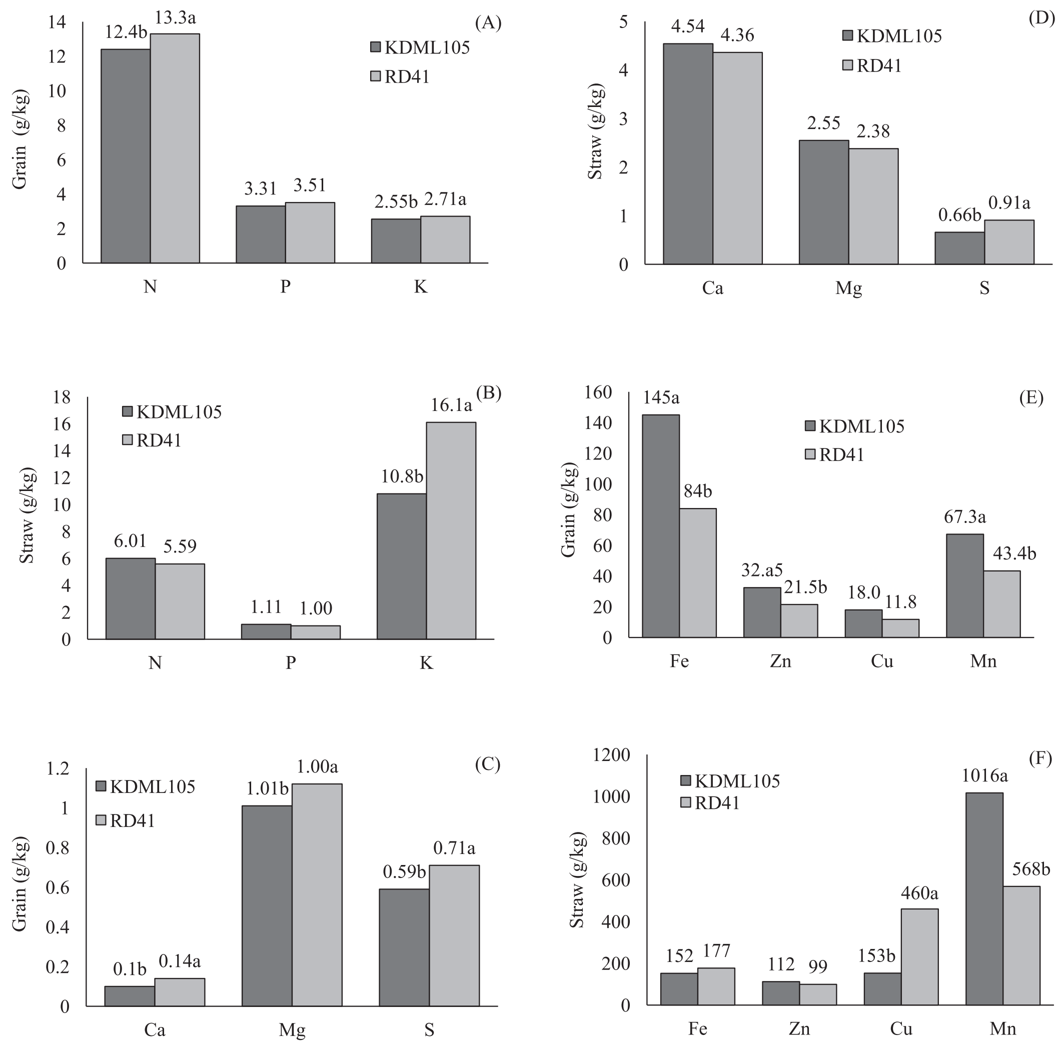

Fig. 1. Comparison between KDML105 and RD41 rice varieties regarding plant major nutrient concentrations in: (A) grain; (B) straw; minor nutrient concentrations in: (C) grain; (D) straw; micronutrient concentrations in: (E) grain; (F) straw. Note: Cu × 10 values shown. Different lowercase letters on bars grouped under one element are significantly different ($p \le 0.05$).

The rice yield and its yield component consisting of the grain yield adjusted to 14% moisture content, the 100-grain weight, the % filled grain and the weight of dried straw were harvested and measured when the KDML105 was 156 d old and the RD41 was 115 d old. All parameters were analyzed for statistical significance using ANOVA, mean separation and Duncan's multiple range test (SAS Institute, 2003) were considered significant at the $p \le 0.05$ level and highly significant at the $p \le 0.01$ level (Steel and Torrie, 1987).

Results and discussion

Grain yield and yield components

The KDML105 and RD41 varieties responded to the different applications of composted pig manure and fertilizers with some exceptions regarding the grain yield and %filled grain. There was no statistical difference in the grain yield obtained from both varieties, though KDML105 (1.32 t/ha) had a slightly higher yield than RD41 (1.28 t/ha) as shown in Table 2. However, the yield obtained from both varieties was far below the potential yields of 2.28 t/ha for KDML105 (Sri-aun, 2005; Bureau of Rice Research and Development, 2015a) and 4.51 t/ha for RD41 (Bureau of Rice Research and Development, 2015b) while the average rice yield in the country is 2.33 t/ha (Global Rice Research Partnership, 2013). KDML105 had a highly significantly greater straw weight, plant height, number of filled grains and undeveloped kernels per panicle than did RD41 whereas the latter had higher numbers of tillers per hill, panicles per hill and 100-grain weight than did the former. This was due mainly to their genotypes rather than the effects of fertilization. For example, KDML105 is genetically 140 cm in height and RD41 is 105 cm in height (Bureau of Rice Research and Development, 2015a, b) while the heights recorded in the experiment were 119.2 cm and 70.7 cm, respectively.

The results of the study showed that there was a highly significant response to composted pig manure and chemical fertilizers on the grain yield, straw weight, plant height, numbers of tillers and panicles per hill, while there was no effect of fertilization on the number of filled grains, undeveloped kernels per panicle, %filled grain and 100-grain weight. The applications of composted pig manure at the rate of 3.125 t/ha together with 100% chemical fertilizer at the rate of 187.5 kg/ha (T5) gave the highest grain yield of 1.88 t/ha followed by T3 (100% composted pig manure = 6.25 t/ha) and T6 (50% composted pig manure + 50% chemical fertilizer) that gave yields of 1.73 t/ha and 1.57 t/ha, respectively (Table 2). The two highest yields were highly significantly greater than that of T4 (50%

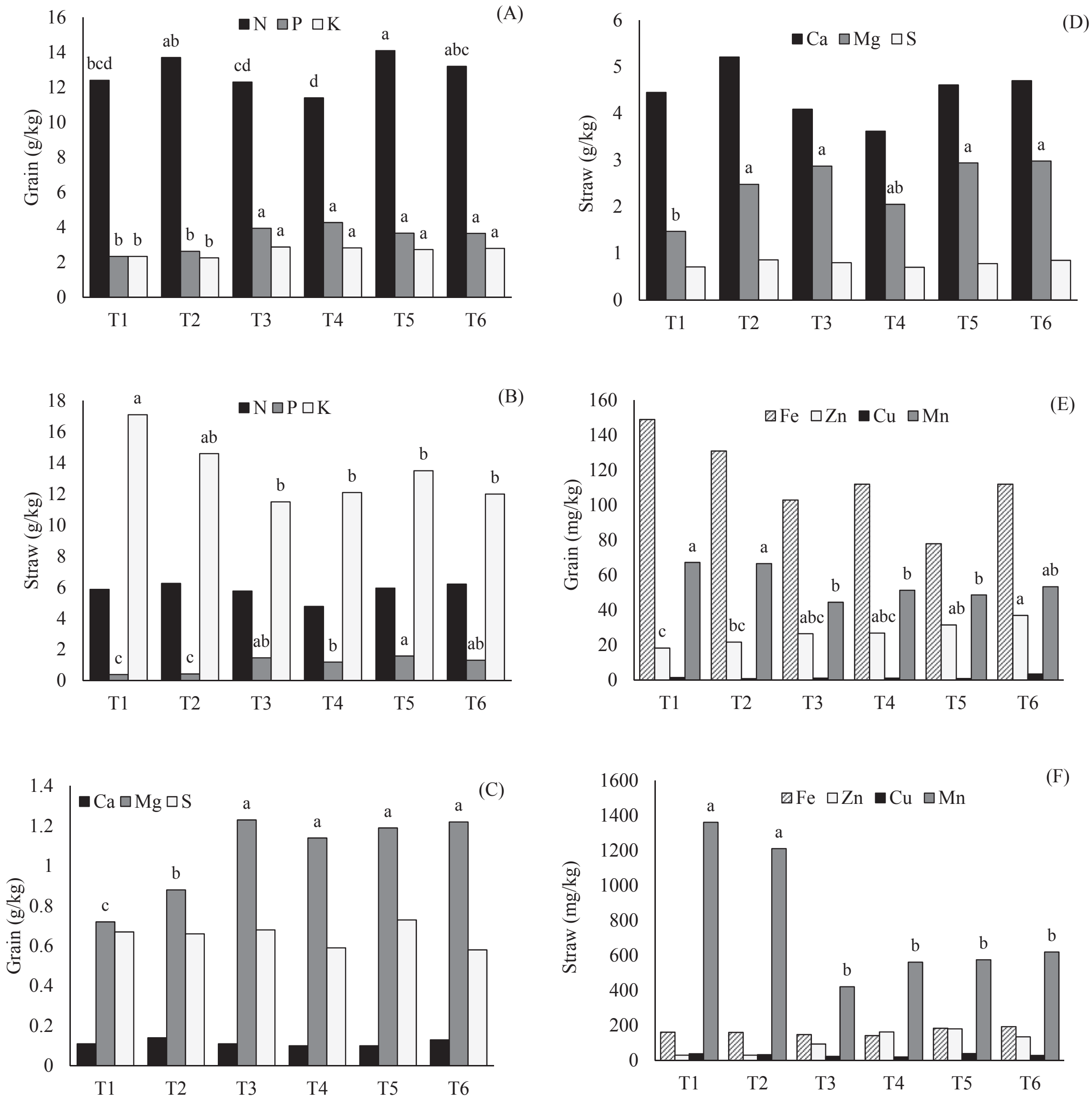

Fig. 2. Effect of different fertilizer treatments on plant major nutrient concentrations in: (A) grain; (B) straw; minor nutrient concentrations in: (C) grain; (D) straw; micronutrient concentrations in: (E) grain; (F) straw. Note: Cu × 10 values shown. Different lowercase letters on bars for the same element in different treatments are significantly different ($p \leq 0.05$).

composted pig manure + 50% chemical fertilizer), T2 (100% chemical fertilizer) and T1 (no fertilization). This indicated that growing rice on Typic Natrustalf cannot obtain a satisfactory yield without fertilization due to the soil having several constraints such as an unfavorable pH, inability to retain moisture and plant nutrients, and a high amount of sodium. Sole application of 100% chemical fertilizer to this soil barely increased the rice grain yield (1.03 t/ha) which was almost similar to that obtained from the treatment with 50% composted pig manure alone (1.05 t/ha). This illustrated that the soil was unable to retain applied fertilizer, while nutrients taken up by the plant increased when enhanced with organic manure as shown by the results. The sole addition of 50% composted pig manure also supported insufficient amounts of plant nutrients for rice even though there was a high CEC (41.9 $cmol_c$/kg) with high nitrogen (3.67%) and phosphorus (4.24%) but very low potassium (0.07%) regardless of plant minor nutrients and micronutrients. The amount of potassium when 50% composted pig manure was applied may not have been sufficient for growing rice, since the topsoil prior to conducting the experiment had only 16.55 mg/kg of available potassium (Table 1). The straw weight, plant height and numbers of tillers and panicles per hill showed similar trends to the grain yield.

There was only just a sufficient number of tillers per hill so that the interaction between rice variety and fertilizer showed a significant difference. The RD41 variety responded better to fertilization in this context. The application of 50% composted pig manure together with 100% chemical fertilizer (RT5) prompted the RD41 variety to produce the significantly highest number of tillers per hill (18.8 tillers per hill). However, this might have resulted from the variety genetically having a greater number of tillers than the KDML105 variety. While there was no statistical difference, applying 50% composted pig manure and 100% chemical fertilizer (RT5) tended to give the highest gain yield (2.29 t/ha), just slightly more than half of the potential yield of this variety, as mentioned earlier. In the case of KDML105, the application of 50% composted pig manure with 50% chemical fertilizer applied (JT6) seemed to

Table 3
Response of KDML105 and RD41 rice to organic and chemical fertilizers on major plant nutrient uptake in different plant parts.

Treatment	Nitrogen			Phosphorus			Potassium		
	Grain	Straw	Above ground	Grain	Straw	Above ground	Grain	Straw	Above ground
	(kg/ha)								
Rice variety									
KDML105	14.5	14.77^{a}	29.26	3.95	3.02^{a}	6.98	2.99	23.49	26.48
RD41	15.5	8.32^{b}	23.81	4.24	1.76^{b}	6.00	3.14	24.19	27.33
F-test	ns	**	ns	ns	**	ns	ns	ns	ns
Fertilizer									
JT1	6.15^{c}	5.28^{c}	11.44^{c}	1.10^{d}	0.38^{b}	1.47^{c}	1.09^{c}	13.15c	14.24^{b}
JT2	12.70^{bc}	9.54^{bc}	22.24^{bc}	2.38^{cd}	0.66^{b}	3.04^{c}	2.01^{bc}	20.71bc	22.71^{b}
JT3	18.70^{ab}	14.93^{ab}	33.66^{ab}	6.03^{a}	3.73^{a}	9.77^{a}	4.32^{a}	27.44ab	31.78^{a}
JT4	10.50^{c}	7.05^{c}	17.54^{c}	3.91^{bc}	1.78^{b}	5.69^{b}	2.57^{b}	19.04c	21.62^{b}
JT5	23.76^{a}	15.99^{a}	39.75^{a}	6.08^{a}	4.31^{a}	10.39^{a}	4.54^{a}	34.05a	38.58^{a}
JT6	18.11^{ab}	16.44^{a}	34.56^{a}	5.08^{ab}	3.50^{a}	8.59^{a}	3.85^{a}	28.66ab	32.52^{a}
F-test	**	**	**	**	**	**	**	**	**
Interaction: variety × fertilizer									
JT1	9.86	8.08	17.93	1.72	0.65	2.37	1.70	17.34^{bc}	19.03^{de}
JT2	12.54	12.28	24.80	2.03	0.96	3.00	1.86	23.48^{b}	25.33^{bcd}
JT3	17.43	20.39	37.80	5.47	4.84	10.33	4.14	29.22^{b}	33.40^{b}
JT4	10.16	6.79	16.93	3.93	1.65	5.60	2.51	16.90^{bc}	19.43^{cde}
JT5	16.81	17.73	34.53	4.57	5.32	9.87	3.42	25.66^{b}	29.07^{bcd}
JT6	20.20	23.35	43.53	5.99	4.73	10.73	4.30	28.31^{b}	32.63^{bc}
RT1	2.45	2.49	4.94	0.48	0.10	0.58	0.48	8.97^{c}	9.45^{e}
RT2	12.86	6.81	19.67	2.73	0.36	3.09	2.15	17.94^{bc}	20.09^{bcde}
RT3	20.04	9.47	29.52	6.59	2.62	9.21	4.50	25.66^{b}	30.15^{bcd}
RT4	10.84	7.30	18.15	3.88	1.90	5.79	2.64	21.17^{b}	23.80^{bcd}
RT5	30.71	14.26	44.97	7.59	3.31	10.90	5.65	42.43^{a}	48.09^{a}
RT6	16.02	9.55	25.58	4.17	2.28	6.44	3.40	29.01^{b}	32.41^{bcd}
F-test	ns	ns	ns	ns	ns	ns	ns	*	*
%CV	37.6	43.2	36.7	37.8	48.3	30.0	33.4	26.8	25.8

ns = non-significant; *, ** significantly different at 0.05 and 0.01 probability levels, respectively; means with different superscript letters within a column indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.
T1 = no fertilization; T2 = chemical fertilizer (100%); T3 = pig manure (100%); T4 = pig manure (50%); T5 = pig manure (50%) + chemical fertilizer (100%); T6 = pig manure (50%) + chemical fertilizer (50%).
R = RD41 rice variety; J = jasmine rice (KDML105 variety).

suit the soil conditions well, giving the highest yield among those obtained from this variety of 1.88 t/ha. The higher rate of chemical fertilizer with the same amount of composted pig manure (JT5) resulted in an inferior grain yield. This might have been due to KDML105 being an indigenous variety (Sri-aun, 2005) that is well known to respond to quite limited amount of applied nutrients. Thus, this rice variety did not show any increment in the grain yield with an increase in the amount of chemical fertilizer (187.5 kg/ha). This was in contrast to the newly bred variety (RD41) as shown in Table 2.

Nutrient concentration

There were statistically different concentrations between the KDMK105 and RD41 rice varieties in the levels of nitrogen, potassium, calcium, magnesium, sulfur, iron, zinc and manganese in the grain and in potassium, sulfur, copper and manganese in the straw. The concentrations of nitrogen, potassium, calcium, magnesium and sulfur in the grain of the KDML105 variety were significantly lower than in the RD41 variety (Fig. 1A and C). In contrast with regard to micronutrients, the KDML105 variety had highly significantly greater concentrations of iron, zinc and manganese than the RD41 variety (Fig. 1E). However, only the levels of potassium, sulfur and copper had highly significantly greater concentrations in the straw of the RD41 variety than the KDML105 variety while only the manganese concentration in the KDML105 variety was greater than in the RD41 variety (Fig. 1B, D and F).

The application of 50% composted pig manure together with 100% chemical fertilizer (T5) highly significantly promoted rice to have the highest concentration of nitrogen in grain (14.1 g/kg) with no difference among treatments in the case of straw (Fig. 2A, B). However, the concentration in grain obtained from T5 was not different from those applied with 100% chemical fertilizer (T2) and 50% composted pig manure together with 50% chemical fertilizer (T6). Manure and fertilizer had an effect on the phosphorus concentration in the plant parts rather than being dependent on the rice variety. The incorporation of composted pig manure in all treatments highly significantly induced the highest concentration of phosphorus in the grain when compared to the sole application of chemical fertilizer (T2) and the control (T1) as shown in Fig. 2A a much higher phosphorus concentration in the straw was found when 50% composted pig manure plus 100% chemical fertilizer (T5) was applied, with the phosphorus amount (1.58 g/kg) being more than three times higher. The potassium concentration in the grain had the same trend as the nitrogen but the highest concentration of potassium in the straw was surprisingly the greatest in the control (17.1 g/kg). A dilution effect might have played a part due to the biomass obtained from the control being so low. Only the magnesium concentration in the grain and straw demonstrated some differences (Fig. 2C, D), with the application of composted pig manure producing a greater concentration in the grain than no application of the manure (T1 and T2), while in the straw, all plots with manure and fertilizer applied had highly significantly greater concentration of this plant nutrient than did the control. The use of 50% composted pig manure plus 50%

Table 4
Response of KDML105 and RD41 rice to organic and chemical fertilizers on minor plant nutrient uptake in different plant parts.

Treatment	Calcium			Magnesium			Sulfur		
	Grain	Straw	Above ground	Grain	Straw	Above ground	Grain	Straw	Above ground
	(kg/ha)								
Rice variety									
KDML105	0.11	11.55^{a}	11.67^{a}	1.21	6.67^{a}	7.87^{a}	0.68	1.63	2.31
RD41	0.15	6.44^{b}	6.59^{b}	1.36	3.85^{b}	5.21^{b}	0.73	1.30	2.03
F-test	ns	**	**	ns	**	**	ns	ns	ns
Fertilizer									
T1	0.05^{c}	3.97^{c}	4.01^{c}	0.35^{c}	1.34^{c}	1.69^{c}	0.29^{c}	0.61^{c}	0.89^{b}
T2	0.13^{ab}	8.05^{abc}	8.18^{abc}	0.80^{bc}	3.80^{b}	4.59^{b}	0.61^{abc}	1.24^{bc}	1.86^{ab}
T3	0.18^{a}	11.6^{ab}	11.78^{ab}	1.85^{a}	7.58^{a}	9.44^{a}	1.03^{a}	1.91^{ab}	2.94^{a}
T4	0.09^{bc}	5.53^{bc}	5.63^{bc}	1.04^{b}	3.16^{bc}	4.19^{bc}	0.52^{bc}	1.08^{bc}	1.6^{b}
T5	0.18^{a}	12.59^{a}	12.78^{a}	1.99^{a}	8.18^{a}	10.18^{a}	1.01^{a}	1.77^{ab}	2.77^{a}
T6	0.17^{a}	12.23^{ab}	12.41^{ab}	1.67^{a}	7.47^{a}	9.14^{a}	0.76^{ab}	2.21^{a}	2.96^{a}
F-test	**	*	*	**	**	**	**	**	**
Interaction: variety × fertilizer									
JT1	0.07	5.92	5.97	0.55	2.08	2.63	0.43	0.87	1.30
JT2	0.12	10.20	10.33	0.72	4.73	5.43	0.60	1.33	1.93
JT3	0.13	16.78	16.93	1.74	10.58	12.33	0.90	2.07	2.98
JT4	0.06	5.15	5.23	0.95	3.07	4.00	0.53	0.8	1.33
JT5	0.13	15.78	15.93	1.47	10.26	11.73	0.91	2.19	3.10
JT6	0.17	15.46	15.63	1.81	9.27	11.07	0.68	2.55	3.22
RT1	0.02	2.02	2.05	0.15	0.59	0.75	0.15	0.34	0.49
RT2	0.13	5.89	6.03	0.87	2.88	3.75	0.62	1.16	1.78
RT3	0.22	6.41	6.63	1.96	4.58	6.54	1.16	1.74	2.9
RT4	0.12	5.90	6.02	1.12	3.24	4.37	0.51	1.36	1.87
RT5	0.23	9.40	9.63	2.51	6.11	8.62	1.1	1.34	2.44
RT6	0.17	9.01	9.18	1.53	5.67	7.21	0.83	1.87	2.71
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns
%CV	41.7	58.7	58.04	33.8	37.3	33.9	50.3	48.4	39.6

ns = non-significant; *, ** significantly different at 0.05 and 0.01 probability levels, respectively; means with different superscript letters within a column indicate a significant difference according to Duncan's multiple range test at $p \leq 0.05$.
T1 = no fertilization; T2 = chemical fertilizer (100%); T3 = pig manure (100%); T4 = pig manure (50%); T5 = pig manure (50%) + chemical fertilizer (100%); T6 = pig manure (50%) + chemical fertilizer (50%).
R = RD41 rice variety; J = jasmine rice (KDML105 variety).

chemical fertilizer (T6) significantly enhanced rice to have the greatest concentration of zinc in the grain (Fig. 2E), whereas the highest content in the straw was found in the plot applied with 50% composted pig manure plus 100% chemical fertilizer (T5) as shown in Fig. 2F. It appeared that an insufficient supply of plant nutrients induced the plant to accumulate higher amounts of manganese in the grain and straw than for the other nutrients added.

There was no interaction between the rice variety and fertilizer in the context of plant nutrient concentrations in the grain and straw. Only the potassium concentration in the straw showed a difference among treatments but it seemed that the dilution effect played a part in this as there was no clear trend, considering the rice variety and fertilizer applied.

Plant nutrient uptake

Among the major plant nutrients, potassium was taken up in the greatest amount followed by nitrogen and phosphorus. The two varieties KDML105 and RD41 took up nitrogen in the grain in similar amounts with 14.5 kg/ha and 15.5 kg/ha, respectively. However, the nutrient uptake in the straw by the former variety was highly significantly greater than in the latter variety with contents of 14.77 kg ha^{-1} and 8.32 kg ha^{-1}, respectively (Table 3). There was no statistical difference between these two varieties in terms of nitrogen uptake in the above ground plant. The same trend was found in the uptake of phosphorus, with 3.02 kg/ha of P taken up in the straw by the KDML105 variety which was highly significantly greater than that in the straw of the RD41 variety. There was no difference in potassium in all plant parts between these two rice varieties.

The KDML105 variety was capable of taking up greater amounts of plant minor nutrients, particularly calcium and magnesium in the straw. The uptake of calcium and magnesium in the grain by these two varieties was not significantly different and these two plant nutrients were stored mainly in the straw because calcium is essential for cell elongation and magnesium is responsible for energy transfer within the plant (Havlin et al., 2005), both of which are active in the vegetative part of the plant. The calcium content in the straw of the KDML105 rice variety (11.55 kg/ha) was highly significantly greater than, and almost twice that in the straw of the RD41 variety (6.44 kg/ha) as shown in Table 4. This was also the case for the magnesium uptake in the straw. There was no difference in the sulfur uptake between the two varieties.

Most of the plant micronutrients were taken up by the KDML105 variety in higher amounts than in the RD41 variety with the exception of copper in the straw. The KDML105 variety took up higher amounts of iron in both the grain and straw, and of zinc in the grain and manganese in both the grain and straw than the RD41 variety. This is of importance with regard to storage in the grain because these micronutrients are essential for human well being and the KDML105 variety or jasmine rice containing higher amounts would be more healthy for human consumption of the same amount of either rice variety (see Table 5).

Table 5
Response of KDML105 and RD41 rice to organic and chemical fertilizers on plant micronutrient uptake in different plant parts.

Treatment	Iron			Zinc			Copper			Manganese		
	Grain	Straw	Above ground	Grain	Straw	Above ground	Grain	Straw	Above ground	Grain	Straw	Above ground
	g/ha						mg/ha			g/ha		
Rice variety												
KDML105	153^{a}	402^{a}	555^{a}	39^{a}	280	319	194	347^{b}	541	72^{a}	2117^{a}	2189^{a}
RD41	97^{b}	259^{b}	356^{b}	26^{b}	185	212	123	678^{a}	801	46^{b}	724^{b}	771^{b}
F-test	*	*	**	**	ns	ns	ns	*	ns	**	**	**
Fertilizer												
T1	91	120^{c}	212^{c}	9^{c}	24^{c}	33^{c}	62	258	319	38^{c}	1294	1332
T2	111	251^{bc}	362^{bc}	20^{bc}	49^{c}	69^{c}	63	432	495	56^{abc}	1912	1968
T3	156	391^{ab}	548^{ab}	40^{a}	261^{b}	302^{b}	173	476	649	66^{ab}	1289	1355
T4	117	215^{bc}	332^{c}	25^{b}	246^{b}	272^{b}	106	311	418	44^{bc}	811	856
T5	125	483^{a}	609^{a}	51^{a}	501^{a}	552^{a}	152	1079	1231	77^{a}	1653	1730
T6	149	525^{a}	674^{a}	49^{a}	316^{ab}	365^{ab}	397	518	916	72^{a}	1566	1638
F-test	ns	**	**	**	**	**	ns	ns	ns	*	ns	ns
Interaction: variety × fertilizer												
JT1	162	131	293	15	34	50	99	218	313	66	2175	2241
JT2	138	322	460	25	66	91	98	381	48	68	2695	2763
JT3	134	545	679	47	364	410	122	337	46	74	2124	2198
JT4	164	202	366	31	275	306	112	16	273	50	1032	1082
JT5	114	514	628	46	591	637	95	733	83	78	2472	2550
JT6	207	701.3	909	68	351	420	639	249	89	93	2204	2297
RT1	21	109	130	3	13	16	26	299	324	9	413	422
RT2	83	180	263	15	32	47	27	482	51	44	1128	1172
RT3	179	237	416	33	159	193	223	614	837	57	454	511
RT4	70	228	298	20	218	238	100	462	562	38	591	629
RT5	137	453	590	56	411	467	208	1424	1632	76	833	909
RT6	91	349	440	30	280	310	155	787	942	52	928	980
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
%CV	58.9	46.3	37.4	36.5	67.5	60.7	174.7	91.7	83.8	36.3	44.6	43.9

ns = non-significant; *, ** significantly different at 0.05 and 0.01 probability levels, respectively; means with different superscript letters within column indicate significant difference according to DMRT at $p \leq 0.05$.
T1 = no fertilization; T2 = chemical fertilizer (100%); T3 = pig manure (100%); T4 = pig manure (50%); T5 = pig manure (50%) + chemical fertilizer (100%); T6 = pig manure (50%) + chemical fertilizer (50%).
R = RD41 rice variety; J = jasmine rice (KDML105 variety).

Fertilization evidently had a clear effect on the uptake of plant major nutrients in all plant parts. The application of manure and chemical fertilizers resulted in the rice taking up higher amounts of nitrogen and phosphorus in the grain than in the straw. The potassium uptake showed the opposite trend, mainly being in the straw (Table 3), which is crucial because this plant part remains on the ground and is incorporated into the next crop, which means the majority of the potassium will be returned to the soil. In contrast, most of the nitrogen is taken away in the rice grain. The highest amounts of these plant major nutrients in all plant parts were taken up when applied with 50% composted pig manure and 100% chemical fertilizer (T5). Nevertheless, the amounts were not statistically different from the applications of 100% composted pig manure (T3) and 50% composted pig manure plus 50% (T6). Applying only chemical fertilizer to the rice grown on this soil was not that effective as also shown by the plant uptake results with the amounts of nitrogen, phosphorus and potassium taken up by the rice being lower than in the other three previously mentioned treatments. The results indicated that soil amendment such as by applying composted pig manure can positively retard the loss of plant major nutrients applied, maybe help conserve soil moisture and provide the slow release of some plant nutrients through mineralization so that the nutrients are available during growing stages of rice when grown on this poor soil. Yang et al. (2004) also reported that the incorporation of organic manure significantly increased the N, P, and K uptake by rice plants and facilitated the allocation and transfer of nutrient elements, especially P, to rice ears and grains.

The manure and fertilizers applied had an effect on plant minor nutrient uptake in all plant parts. There was more than 10 times the amount of calcium stored in the straw compared to the rice grain (Table 4). The application of 50% composted pig manure with 100% chemical fertilizer (T5) resulted in the highly significant and greatest amount of calcium (12.78 kg/ha) in the rice plant parts, as was also the case for magnesium (10.18 kg/ha). However, these amounts were similar to those obtained from the plots applied with 100% composted pig manure (T3) and 50% composted pig manure plus 50% chemical fertilizer (T6). Again, the sole application of chemical fertilizer had less effect on calcium and magnesium uptakes when compared to the previously mentioned treatments. With the exception of the control, the amounts of sulfur taken up in the grain were not statistically different among the remaining treatments applied with manure or fertilizer or both, while the content of sulfur in the straw was the highest (2.21 kg/ha) in T6, which had 50% composted pig manure with 50% chemical fertilizer added.

The straw in the treatment applied with 50% composted pig manure with 50% chemical fertilizer (T6) had the greatest amount of iron in the straw (525 g/ha) which was highly significant. The application of 50% composted pig manure with 100% chemical fertilizer (T5) resulted in plant uptake of the greatest amounts of zinc in the grain and straw, and of manganese in the grain. The sole application of chemical fertilizer tended to have a lesser effect to some degree on the micronutrient uptake than the applications involving composted pig manure.

There was no interaction between the rice variety and fertilizer in the cases of nitrogen and phosphorus, whereas in contrast, the application of 50% composted pig manure together with 100% chemical fertilizer (RT5) significantly promoted the RD41 variety to take up the highest amount of potassium in the straw (42.43 kg/ha), which was far greater than in the other treatments. This coincided with the highest grain yield obtained. The application of 100% composted pig manure (JT3) seemingly encouraged the KDML105 variety to take up more potassium when compared to the other treatments. Applying manure at 6.25 t/ha may have been sufficient to supply potassium slowly to this rice variety and the effectiveness was identical to the application of 100% chemical fertilizer in the case of this plant major nutrient uptake. No interaction between the rice variety and fertilizer was found with calcium, magnesium and sulfur uptakes in all plant parts, which was also the case for the micronutrients.

The KDML105 and RD41 rice varieties responded to composted pig manure and chemical fertilizers in a similar manner with regard to the grain yield when grown on the Typic Natrustalf at Lopburi province. However, other parameters indicated that there were different responses, particularly the KDML105 variety which had the greater straw weight, plant height, numbers of filled grain and undeveloped kernels per panicle than the KD41 variety. Composted pig manure and chemical fertilizers had effects on the grain yield, straw weight, plant height, numbers of tillers and panicles. The application of 50% pig manure plus 100% chemical fertilizer gave the greatest grain yield, straw weight, plant height, numbers of tiller and panicles, being superior to the normal practice (100% chemical fertilizer) used by local farmers, whereas no fertilization promoted the poorest results. No interaction between the rice variety and fertilization was found. Plant major and minor nutrients tended to concentrate in the grain of RD41 in greater amounts than that in the grain of KDML105 whereas most micronutrients showed the opposite trend. The KDML105 variety took up higher amounts of nitrogen, phosphorus, calcium, iron and manganese to store in the straw than did the other variety with no differences in the grain uptake for these nutrients. Both rice varieties had the highest uptake of nitrogen in the grain when applied with 50% pig manure together with 100% chemical fertilizer but the amount did not differ from the addition of either 100% pig manure or 50% pig manure plus 50% chemical fertilizer. The uptake of nitrogen in the straw and in the aboveground plant parts (grain + straw) was likewise. Almost the same trend was also found with the phosphorus, potassium, calcium, magnesium, sulfur, iron and zinc uptakes. The RD41 variety took up the highest amount of potassium in the aboveground plant parts when added with 50% pig manure plus 100% chemical fertilizer, because of the substantial amount of this nutrient being stored in the straw. It was noticeable that the application of 100% pig manure, 50% pig manure together with 100% chemical fertilizer or 50% pig manure plus 50% chemical fertilizer enhanced the rice to take up the highest amounts of zinc, copper and manganese in the grain.

Conflict of interest statement

The authors declare that there are no conflicts of interest.

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