International Journal of Agricultural Technology 2022Vol. 18(1):293-310
Available online http://www.ijat-aatsea.com
ISSN 2630-0192 (Online)

Effects of chicken manure and chemical fertilizer on Growth and Yield of Japonica Rice

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Phopaijit, S., Suraphonphinit, A. and Phakamas, N. (2022). Effects of chicken manure and chemical fertilizer on growth and yield of Japonica rice. International Journal of Agricultural Technology 18(1):293-310.

Abstract Organic and inorganic nitrogen fertilizers are normally used in Indica rice (*Oryza sativa* L.) production system, but information on the effects of chicken manure on Japonica rice is limited. The effects of chicken manure and chemical fertilizers on growth and yield of Japonica rice were determined. Rice varieties were significantly different for most traits including plant height, crop growth rate (CGR), biomass, percentage of filled and unfilled grain, number of grains per spikelet and harvest index (HI), except for grain yield. Chemical fertilizer had the highest grain yield followed by chicken manure, non-treated control and chemical fertilizer together with chicken manure, respectively. The interaction effects between fertilizer treatment and rice variety were not significant for all characters. These rice varieties seemed to better respond to chemical fertilizer than chicken manure treatments.

Keywords: Crop growth rate, Organic fertilizer, Rice production system

Introduction

Rice (*Oryza sativa* L.) is a staple grain food crop that feeds more than half of the world population (Ricepedia, 2021). Indica rice is cultivated in tropical regions, while Japonica rice is cultivated in the temperate regions (Cordero-Lara, 2020). Japonica rice is consumed in most parts of the world including Thailand and other Asian countries, and the market for this type of rice is expanding. Kousei (2010) had reported since 2007 that the number of Japanese restaurants in Thailand has increased and the demand for Japonica rice Thailand has increased by 20 percent annually. Import of Japonica rice from temperate regions is not economical and incurs the overhead costs including tax and transportation cost, causing high retail price in Thailand markets. The expansion of demand for Japonica rice in Thailand opens an opportunity for Thai farmers to produce Japonica rice for local consumption or export.

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In Thailand, Japonica rice is produced mainly in the North such as Chiang Rai province which is a hub of Japonica rice production because the climate is most suitable for cultivation. However, Japonica rice is also produced in some provinces in the lower part of the North and the Northeast regions, but the production is less in other parts of the country. According to Warinrak (2012), the Department of Agriculture recommended that two Japonica rice varieties including DOA1 (Sasanishiki) and DOA2 (Akitakomachi) for cultivation should be cultivated in Thailand. DOA1 is suitable for planting in the North and Northeast, while DOA2 is recommended for planting in upper part of the North. However, many Japonica rice varieties are recommended by private sectors.

Thailand is a leading rice producing country for decades. However, there is increasing competition for export of rice in the world market because many rice producing countries have excess supply. Moreover, rice price is often fluctuated and slump in some years, and the farmers are at risk. Production of Japonica rice can diversify to rice products and reduce the risk especially for organic Japonica rice which is considered to be a specialty product for special consumer segment with high market price.

Central plain is the capital city of rice production in Thailand because it covers the most irrigated areas of the country. This region should be promising for Japonica rice production, if other limiting factors are overcome and the production can be made at low cost. High temperature would be concerned to be the most limiting factor for Japonica rice grown in the tropics (Saichompoo *et al*., 2021). Fertilizers for nitrogen is the most demanding factor incurring high production cost, and improving nitrogen utilization is important for the economic sustainability of crop production systems (Amanullah *et al*., 2010).

Proper management of nitrogen fertilizers using good nitrogen sources and appropriate rates will increase the efficiency of nitrogen utilization and crop yield and reduce production costs and environmental pollution (Fageria *et al*., 2011). However, chemical fertilizers are not allowed for organic rice production. Therefore, organic fertilizers such as yard manure, compost and green manure are applied in organic rice production system and should reduce production costs.

Chicken manure is locally available organic fertilizer that can greatly reduce a farmer’s production cost. Chicken manure contains 4.87 % nitrogen, 4.56% phosphorus and 2.14% potassium (Moe *et al*., 2020). Organic fertilizers not only provide nutrients to the soil, but also improve water retention capacity and increase the air in the soil. It is also suitable for seed germination and root development (Zia *et al*., 1998). The use of manure sometimes has lower yield than chemical fertilizers in the first year, but longterm application of organic fertilizers promise to increase yield. The longterm application of manure for 5 years resulted in better soil quality than the application of chemical fertilizers (Whitney *et al*., 1950). The application of organic fertilizers is an alternative way for farmers to reduce the cost of rice production and the impact on environments in case organic fertilizers are freely available or available at low cost.

Organic fertilizers contain very low macronutrients but they can provide adequate micronutrients to the crops, the application of chemical fertilizers in combination with organic fertilizers might be appropriate for fertilizer management. The question underlying the research project was that how Japonica rice responds to chicken manure and chemical fertilizers after application alone or in combination under high temperature in the central region of Thailand. The objective of this study was to determine the effects of chicken manure and chemical fertilizer on growth and yield of Japonica rice.

Materials and methods

Location and experimental design

Pot experiment was conducted in the open environment at the Department of Plant Production Technology, School of Agricultural Technology, King Mongkut's Institute of Technology Ladkrabang (Latitude: 13.7440 Longitude: 100.7920), during December, 2020 to April, 2021. A 2×4 factorial experiment was set up in a completely randomized design (CRD) with 4 replications. Two Japonica rice varieties consisting of DOA1 and DOA2 were assigned as factor A, and four fertilizer treatments including non-fertilized control, chemical fertilizer, chicken manure and chemical fertilizer plus chicken manure were assigned as factor B.

Soil preparation, planting and cultural practices

Clay soil was collected from the field, air-dried under shade for a week and crushed into small particles. The crushed soil was loaded into plastic pots with 15-inches in diameter and 10 inches in height. Each pot contained 13 kg soil. Soil sample was sent to soil laboratory for analysis of the physical and chemical properties before planting. Soil sample was analysed for soil chemical properties, and the results of soil analysis included 4.77 soil pH, 0.73 mS/cm electrical conductivity (EC) and 2.71 % organic matter (OM). Macro and micro elements consisted of 75.4 ppm phosphorus (P), 190.30 ppm potassium (K), 1,314.54 ppm calcium (Ca) and 0.12 % total nitrogen (N) (Data not shown).

Two fertilizer treatments with chicken manure including chicken manure alone and chemical fertilizer plus chicken manure were prepared for two weeks before transplanting. Chicken manure at the predetermined rates according to the treatments was incorporated into the soil and loaded into the containers. The mixed soils were then fermented for 14 days before planting. The seeds of two Japonica rice were immersed into the water 24 hours. After immersion into the water, the seeds were covered with wet cloth for 24 hours. Pre-germinated seeds were planted with 1-2 seeds per hill in seedling trays for 25 days, and the seedlings were transplanted on 22 January 2021 in the containers at the rate of one seedling for a container.

For the chemical fertilizer treatment alone, chemical fertilizer formula 16-20-0 of N-P_2O_5-K_2O at a rate of 218.75 kg ha^{-1} was applied at 1 days before planting and urea (46-0-0) at a rate of 43.75 kg ha^{-1} was applied at two splits at 20 and 40 days after planting. For chemical fertilizer plus chicken manure treatment, chicken manure at the rate of 1,875 kg ha^{-1} was applied to the crop at 14 days before planting, and urea at the rate of 43.75 kg ha^{-1} was applied to the crop at two splits at 20 and 40 days after planting. For chicken manure alone, chicken manure at the rate of at the rate of 1,875 kg ha^{-1} was applied to the crop at 14 days before planting. The chemical fertilizer formula 16-20-0 of N-P_2O_5-K_2O was applied to the crop at the amount of 1.53 g $container^{-1}$, urea was applied to the crop at the amount of 0.66 g $container^{-1}$, and chicken manure was applied to the crop at the amount of 13.13 g $container^{-1}$. Chicken manure was incubated under saturated soil moisture for 14 days before transplanting. The amounts of fertilizers were calculated for each time of application. Chicken manure was collected from the nearby farm in the dry form and chemical compositions of the manure were not analyzed. Fertilizer was calculated for each container based on the area of the container. Irrigation water was monitored regularly and maintained the level of 10 mm above the soil surface.

Data collection and data analysis

The crop was harvested on 29 April 2021. Data were recorded at harvest for plant height, plant dry weight, number of spikelets per plant, number of grains per spikelet, percentage of filled grains, percentage of unfilled grains, 1,000-grain weight and grain yield. The samples were oven-dried at 80 ^{o}C for 48 hours or until dry weights were constant, and the dry weights of the samples were recorded. The data were derived for harvest index (HI) as follows:

$$HI = (\text{Economic yield}/ \text{Total biological yield}),$$

(Where, Economic yield are seed yield in g plant^{-1} and Total biological yield are seed yield + dry stover yield in g plant^{-1}).

The data were derived for crop growth rate (CGR) as follows;

$$CGR = 1/A \times [(W2- W1)/(T2-T1)],$$

(Where, A is the land area, W2 and W1 are dry weights of plant at time T2 and T1, respectively).

Weather data for the experimental site were obtained from NASA (2021) (Figure 1).

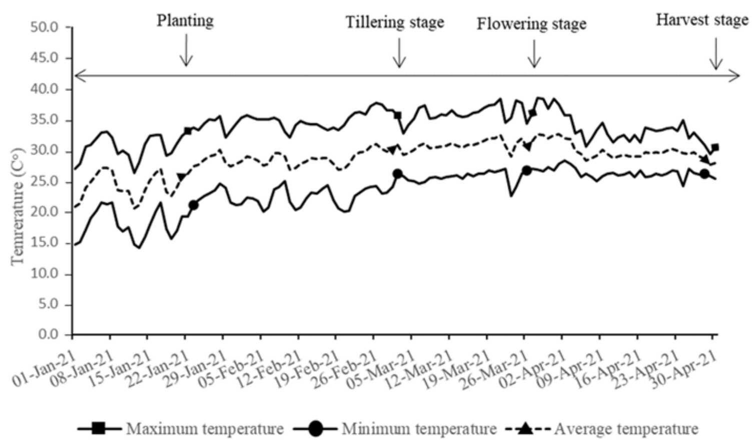

Figure 1. Maximum, minimum and average temperature during growing period (NASA, 2021)

The data were analyzed statistically according to a 2×4 factorial experiment in a completely randomized design. The differences among or treatment means were compared by Duncan's New Multiple Range Test (DMRT) at 0.05 probability level. All statistical analyses were accomplished using M-STATC program from Michigan State University (Bricker, 1989).

Results

Number of spikelets per plant

Fertilizer treatments were significantly different ($P \leq 0.01$) for number of spikelets per plant, and rice varieties were not significantly different for this trait, whereas the interaction between variety and fertilizer was not significant (Table 1). Numbers of spikelets ranged between 6.00 and 11.87 spikelets per plant. Chemical fertilizer was highest (11.87 spikelets per plant), chicken manure alone was intermediate (9.00 spikelets per plant), whereas unfertilized control and chemical fertilizer plus chicken manure were lowest (6.00 spikelets per plant). DOA1 and DOA2 had similar number of spikelets per plant (7.87 for DOA1 and 8.56 for DOA2), and no significant interaction indicated that they performed in a similar pattern for all fertilizer treatments.

Table 1. Means for number of spikelets per plant of two Japonica rice varieties as affected by chemical and organic fertilizer treatments

Fertilizer form (F)	Number of spikelets per plant		
	Variety (V)		
	DOA1	DOA2	**Mean**
Un-fertilized (Control)	6.00	6.00	6.00^{b}
Chemical fertilizer	11.00	12.75	11.87^{a}
Chicken manure	9.50	8.50	9.00^{ab}
Chemical fertilizer plus chicken manure	5.00	7.00	6.00^{b}
Mean	7.87	8.56	
F-Test			
Variety (V)	ns		
Fertilizer form (F)	**		
V × F	ns		
C.V. (%)	39.80		

ns = non-significant
** = significantly different at P ≤ 0.01
Means within the same column followed by the same letter are not significantly different by DMRT

Number of grains per spikelet

Fertilizer treatments were not significantly different for number of grains per spikelet, but two rice varieties were significantly different (P≤0.05) for this trait, whereas the interaction between variety and fertilizer treatment was not significant (Table 2). Numbers of grains per spikelet among fertilizer treatments ranged from 38.20 to 45.60 spikelets, and numbers of spikelets for two rice varieties were 48.79 and 33.55 spikelets for DOA1 and DOA2, respectively. The range of spikelet numbers was between 38.20 and 45.60 spikelets. Although fertilizer treatments were not significantly different, chicken manure alone seemed to be better than other treatments for number of spikelets (45.60 spikelets per plant). Varieties performed similarly across fertilizer treatments as the interaction between variety and fertilizer treatment was not significant.

Table 2. Means for number of grains per spikelet of two Japonica rice varieties as affected by chemical and organic fertilizer treatments

Fertilizer form (F)	Number of grains per spikelet Variety (V) DOA1	 DOA2	Mean
Un-fertilized (control)	47.91	29.01	38.46
Chemical fertilizer	47.63	37.21	42.42
Chicken manure	55.11	36.09	45.60
Chemical fertilizer plus chicken manure	44.50	31.91	38.20
Mean	48.79^{A}	33.55^{B}	
F-Test			
Variety (V)		*	
Fertilizer form (F)		ns	
V x F		ns	
C.V. (%)		18.88	

ns = non-significant ; * = significantly different at P≤ 0.05
Means within the same column followed by the same letter are not significantly different by DMRT

Crop growth rate

Fertilizer treatments were significant different (P≤0.01) for crop growth rate (CGR), and the significant difference (P≤0.05) was also observed between two rice varieties, whereas the interaction between fertilizer treatment and rice variety was not significant (Table 3). Crop growth rates among fertilizer treatments ranged between 1.43 and 3.54 g m^{-2} d^{-1}, and chemical fertilizer was highest (3.54 g m^{-2} d^{-1}), whereas un-fertilized control was lowest (1.43 g m^{-2} d^{-1}). DOA1 had significantly higher crop growth rate (2.59 g m^{-2} d^{-1}) than DOA2 (1.86 g m^{-2} d^{-1}). Similar responses to fertilizer application were observed between two rice varieties.

Table 3. Means for crop growth rate (CGR) during transplanting to harvest of two Japonica rice varieties at harvest stage as affected by chemical and organic fertilizer treatments

Fertilizer form (F)	CGR during transplanting to harvest (g m^{-2} d^{-1}) Variety (V) DOA1	 DOA2	Mean
Un-fertilized (control)	1.75	1.11	1.43^{b}
Chemical fertilizer	3.82	3.26	3.54^{a}
Chicken manure	3.04	1.82	2.43^{ab}
Chemical fertilizer plus chicken manure	1.75	1.25	1.50^{b}
Mean	2.59^{A}	1.86^{B}	
F-Test			
Variety (V)		*	
Fertilizer form (F)		**	
V × F		ns	
C.V. (%)		38.67	

ns = non-significant ; * = significantly different at P≤ 0.05; ** = significantly different at P ≤ 0.01
Means within the same column followed by the same letter are not significantly different by DMRT

Straw dry weight

The main effects of both fertilizer and variety on straw dry weight were significant (P≤0.01 for both fertilizer and variety) (Table 4). Straw dry weights among fertilizer treatments varied between 8.20 and 19.05 g plant^{-1}, and chemical fertilizer had the highest straw weight of 19.05 g plant^{-1}, whereas un-fertilized control had the lowest straw weight of 8.20 g plant^{-1}. DOA1 had straw weight of 15.52 g plant^{-1}, whereas DOA2 had straw weight of 9.75 g plant^{-1}. As the interaction between variety and fertilize was not significant, the rice varieties had similar responses to fertilizer application for straw weight.

Table 4. Means for straw weight of two Japonica rice varieties as affected by chemical and organic fertilizer treatments

Fertilizer form (F)	**Straw weight (g plant^{-1})** Variety (V)		**Mean**
	DOA1	DOA2	
Un-fertilized (control)	10.44	5.96	8.20^{b}
Chemical fertilizer	21.19	16.92	19.05^{a}
Chicken manure	18.28	9.16	13.72^{ab}
Chemical fertilizer plus chicken manure	12.17	6.95	9.56^{b}
Mean	15.52^{A}	9.75^{B}	
F-Test			
Variety (V)		**	
Fertilizer form (F)		**	
V × F		ns	
C.V. (%)		31.78	

ns = non-significant
** = significantly different at P ≤ 0.01
Means within the same column followed by the same letter are not significantly different by DMRT

Grains dry weight

The effect of variety on grain dry weight was not significant, whereas the effect of fertilizer was significant (P≤0.01) (Table 5). DOA1 had grain dry weight of 6.26 g plant^{-1}and DOA2 gad grain dry weight of 5.80 g plant^{-1}, which were not statistically different. The highest grain dry weight was observed in chemical fertilizer (10.67 g plant^{-1}) followed by chicken manure (6.49 g plant^{-1}), whereas the lowest grain dry weight was found in chemical fertilizer plus chicken manure (2.97 g plant^{-1}), which was not statistically different from un-fertilized control (3.98 g plant^{-1}). Non significant interaction between variety and fertilizer indicated the lack of differential response of varieties for grain dry weight across fertilizer treatments.

Table 5. Means for grain dry weight of two Japonica rice varieties as affected by chemical and organic fertilizer treatments

Fertilizer form (F)	Grain dry weight (g plant^{-1}) Variety (V)		Mean
	DOA1	DOA2	
Un-fertilized (control)	4.54	3.43	3.98^{b}
Chemical fertilizer	11.02	10.32	10.67^{a}
Chicken manure	6.99	5.98	6.49^{ab}
Chemical fertilizer plus chicken manure	2.48	3.45	2.97^{b}
Mean	6.26	5.80	
F-Test			
Variety (V)	ns		
Fertilizer form (F)	**		
V × F	ns		
C.V. (%)	63.52		

ns = non-significant ; ** = significantly different at P ≤ 0.01
Means within the same column followed by the same letter are not significantly different by DMRT

Biomass

The effect of fertilizer and the effect of variety were significant (P≤0.01 for fertilizer and P≤0.05 for variety) for biomass (Table 6). The highest biomass was obtained from chemical fertilizer (29.72 g plant^{-1}) followed by chicken manure (20.21 g plant^{-1}), whereas the lowest biomass was obtained from un-fertilized control (12.18 g plant^{-1}). DOA1 (21.77 g plant^{-1}) was significantly higher than DOA2 (15.54 g plant^{-1}) for biomass. Non-significant interaction between variety and fertilizer indicated the similar responses of varieties to fertilizer application.

Table 6. Means for biomass of two Japonica rice varieties as affected by chemical and organic fertilizer treatments

Fertilizer form (F)	Biomass (g plant^{-1}) Variety (V)		Mean
	DOA1	DOA2	
Un-fertilized (control)	14.98	9.39	12.18^{b}
Chemical fertilizer	32.20	27.24	29.72^{a}
Chicken manure	25.27	15.14	20.21^{ab}
Chemical fertilizer plus chicken manure	14.65	10.40	12.53^{b}
Mean	21.77^{A}	15.54^{B}	
F-Test			
Variety (V)	*		
Fertilizer form (F)	**		
V × F	ns		
C.V. (%)	38.35		

ns = non-significant
* = significantly different at P≤ 0.05
** = significantly different at P ≤ 0.01
Means within the same column followed by the same letter are not significantly different by DMRT

Percentage of filled grain

The effect of fertilizer and the effect of variety were significant (P≤0.05 for both main effects) for percentage of filled grains (Table 7). Chemical fertilizer had the highest percentage of filled grains of 68.89% followed by un-fertilized control (66.76%) and chicken manure (64.78%), whereas chemical fertilizer plus chicken manure had the lowest percentage of filled grains (45.03%), which as significantly lower than chemical fertilizer. DOA3 had significantly higher percentage of filled grains (66.52%) than DOA1 (50.25%). These varieties had similar responses to fertilizer application.

Percentage of unfilled grain

The effect of fertilizer and the effect of variety were significant (P≤0.05 for both main effects) for percentage of unfilled grains (Table 8). The highest percentage of unfilled grains (54.59%) was obtained from chemical fertilizer plus chicken manure followed by chicken manure (47.12%), whereas chemical fertilizer and chemical fertilizer had the lowest percentages of unfilled grains of 21.11 and 33.24%, respectively. Greater percentage of unfilled grains (49.74%) was also obtained from DOA1 compared to DOA2 (33.48%). Both DOA1 and DOA2 performed in a similar pattern for percentage of unfilled grains.

Table 7. Means for percentage of filled grains of two Japonica rice varieties as affected by chemical and organic fertilizer treatments

Fertilizer form (F)	Percentage of filled grains (%)		
	Variety (V)		
	DOA1	DOA2	Mean
Un-fertilized (control)	60.33	73.19	66.76[a]
Chemical fertilizer	68.66	69.12	68.89[a]
Chicken manure	35.61	70.14	64.78[ab]
Chemical fertilizer plus chicken manure	36.42	53.63	45.03[b]
Mean	50.25[B]	66.52[A]	
F-Test			
Variety (V)	*		
Fertilizer form (F)	*		
V × F	ns		
C.V. (%)	27.74		

ns = non-significant

* = significantly different at P≤ 0.05

Means within the same column followed by the same letter are not significantly different by DMRT

Table 8. Means for percentage of unfilled grains of two Japonica rice varieties as affected by chemical and organic fertilizer treatments

Fertilizer form (F)	Percentage of unfilled grains (%)		Mean
	Variety (V)		
	DOA1	DOA2	
Un-fertilized (control)	39.67	26.81	33.24^{b}
Chemical fertilizer	31.34	30.88	31.11^{b}
Chicken manure	64.39	29.86	47.12^{ab}
Chemical fertilizer plus chicken manure	63.58	46.37	54.98^{a}
Mean	49.74^{A}	33.48^{B}	
F-Test			
Variety (V)		*	
Fertilizer form (F)		*	
V × F		ns	
C.V. (%)		44.76	

ns = non-significant
* = significantly different at P≤ 0.05
Means within the same column followed by the same letter are not significantly different by DMRT

1,000-grain weight

Fertilizer significantly (P≤0.01) affected the variation in 1,000-grain weight, whereas the variation in 1,000-grain weight as affected by variety was not significant (Table 9). The highest 1,000-grain weights (24.79 g) were obtained from chemical fertilizer followed by chicken manure (23.80 g), and the lowest 1,000-grain weights were obtained from chemical fertilizer plus chicken manure (20.38 g) followed by un-fertilized control (23.26g). 1,000-grain weight of DOA1 was 22.42%, and 1,000-grain weight of DOA2 was 23.69%. These varieties were similar for 1,000-grain weight and performed similarly across fertilizer treatments.

Harvest index

Fertilizer application did not cause significant variation in harvest index (HI) (Table 10). Harvest indexes among four fertilizer treatments ranged between 0.19 and 0.29. However, significant (P≤0.05) variation in harvest index was observed between two rice varieties. DOA2 had significantly higher harvest index (0.30) than DOA1 (0.22). These rice varieties responded similarly to fertilizer application.

Table 9. Means for 1,000-grain weight of two Japonica rice varieties as affected by chemical and organic fertilizer treatments

Fertilizer form (F)	**1,000-grain weight (g)** Variety (V)		**Mean**
	DOA1	DOA2	
Un-fertilized (control)	22.93	23.60	23.26[ab]
Chemical fertilizer	24.48	25.10	24.79[a]
Chicken manure	23.05	24.55	23.80[a]
Chemical fertilizer plus chicken manure	19.23	21.53	20.38[b]
Mean	22.42	23.69	
F-Test			
Variety (V)		ns	
Fertilizer form (F)		**	
V × F		ns	
C.V. (%)		9.90	

ns = non-significant
** = significantly different at $P \leq 0.01$
Means within the same column followed by the same letter are not significantly different by DMRT

Table 10 Means for harvest index of two Japonica rice varieties as affected by chemical and organic fertilizer treatments

Fertilizer form (F)	**Harvest index** Variety (V)		**Mean**
	DOA1	DOA2	
Un-fertilized (control)	0.24	0.32	0.28
Chemical fertilizer	0.27	0.32	0.29
Chicken manure	0.23	0.34	0.28
Chemical fertilizer plus chicken manure	0.13	0.25	0.19
Mean	0.22[B]	0.30[A]	
F-Test			
Variety (V)		*	
Fertilizer form (F)		ns	
V × F		ns	
C.V. (%)		40.45	

ns = non-significant
* = significantly different at $P \leq 0.05$
Means within the same column followed by the same letter are not significantly different by DMRT

Discussion

This study investigated the possibility to produce organic Japonica rice in the central plain of Thailand, which covers most irrigated area of the country.

Japonica rice is cultivated in temperate regions, while Indica rice is cultivated in the tropics (Cordero-Lara, 2020). In Thailand, Japonica rice is produced in the North, where the temperature is lower than other parts of the country. The authors selected planting dates in the dry season to understand how high temperatures during vegetative phase affects grain yield and yield component of Japonica rice. The authors were also interested in comparing organic fertilizer and chemical fertilizer to find the suitable methods for fertilizer management to obtain maximum yield. The results in this study would be beneficial to rice growers who can make decision on which fertilizer management strategies are suitable for Japonica rice production for both organic and inorganic production systems.

In this study, application of different methods of fertilization significantly affected number of spikelets per plant, CGR during transplanting to harvest, straw weight, grain dry weight, biomass, percentage of filled grains, percentage of unfilled grains and 1,000-grain weight, but it did not significantly affected number of grains per spikelet and harvest index. Kakar *et al*. (2020) found that the greatest panicle number, spikelet number, and grain yield were recorded in animal manure plus 50% of traditional chemical rate and sawdust plus 50% of traditional chemical rate.

In general, chemical fertilizer alone and chicken manure alone were better than unfertilized control for most parameters except for percentage of filled grains and percentage of unfilled grains, which were similar. The results might indicate that in Japonica rice is not responsive to fertilizer application for percentage of filled grains and percentage of unfilled grains. According to Gharib *et al*. (2011) number of filled grains per panicle and number of unfilled grains per panicle increased with nitrogen application from 50 to 200 kg ha^{-1}, but nitrogen application did not significantly affected percentage of filled grains and percentage of unfilled grains. Mahmud *et al*. (2016) also found that application of medium level of chemical fertilizer with 4 t ha^{-1} vermicompost gave the maximum yield and over dose of NPKS fertilizers from chemical source decreased rice yield.

Better performance of chemical fertilizer alone than other treatments was not surprising because chemical fertilizer is an important source of macronutrients required by plant. However, chicken manure has rather small amounts of macronutrients compared to chemical fertilizers, but it provides sufficient micronutrients to the crop (Dróżdż *et al*., 2020).

Chemical fertilizer plus chicken manure in general performed poorer than other treatments for most parameters, and it also had the highest percentage of un-filled grains. The results were rather against the theoretical expectation, and the authors did not find a good explanation. In theory, the treatment should be better than chicken manure alone because additional urea was applied into the crop. Additional of chicken manure would cause excessive nutrients to the crop as chicken manure is rich in nitrogen, phosphorus and potassium (Parker *et al*., 1959).

From our observation, the crop was infested by some insect pests at early growth stages and bacterial leaf blight also occurred. Disease and insect outbreak may confound the results. The yield loss estimated on the attainable yield using regression models ranged from 31 to 44% (Rajarajeswari and Muralidharan, 2006), while insect pests caused yield loss by 27.9% (Mondal *et al*., 2017).

Moreover, the soil used in this study was rather fertile, and most soil nutrients were rather high. However, the soil had rather low pH, that may limit the release of some nutrients, and the crop may have low response to input fertilizers. Alia *et al*. (2015) found that low pH soil increased the release of aluminium and iron that were toxic to rice. Based on our results chicken manure could be used as an alternative organic fertilizer for Japonica rice production. However, strong conclusion can be made after verification of the results in larger scales, and field experiments should also be conducted. The investigations of different sources of organic fertilizers and different rates are still required.

DOA1 and DOA2 were selected in this study because they are the recommended varieties suitable for Japonica rice production in Thailand. These varieties were different in heat tolerance levels. According to Warinrak (2013), DOA1 is more tolerant to heat stress than DOA2 as it had better yield in the lower regions of the North, while DOA2 has higher yield in the upper regions of the North with lower temperature. In this study, two rice varieties were significantly different for number of grains per spikelet, CGR during transplanting to harvest, straw weight, biomass, percentage of filled grain, percentage of unfilled grain and harvest index. However, they performed similarly for number of spikelets per plant, grain dry weight and 1,000-grain weight. DOA1 was higher than DOA2 for number of grains per spikelet, CGR during transplanting to harvest, straw weight, biomass and percentage of unfilled grains, whereas DOA2 was higher than DOA1 for percentage of filled grains and harvest index.

In temperate region in China, Japonica/Indica hybrids had higher grain yields than Japonica rice, ranging from 38.3 to 75.6% (Sun *et al*., 2020). The utilization of hybrid varieties as a strategy to increase yield of Japonica rice in tropical climate is worth exploring. DOA1 had grain dry weight of 6.26 g/plant and DOA2 had grain dry weight of 5.80 g $plant^{-1}$, showing similar performance for grain yield. However, they used different strategies to obtain grain yield.

DOA1 had better growth and accumulated high biomass, whereas DOA2 had smaller plants but it was more tolerant to heat stress as indicated by its higher percentage of filled grains and harvest index. The temperate region in grain dry weights per plant of Japonica rice ranged between 5.0 and 11.0 g plant^{-1} and 10.0 and 16.0 g plant^{-1}, depending on soil fertility of the tested sites (Yang *et al*., 2002). The crop grown under temperate condition was more productive than that grown under tropical condition.

As Japonica rice is produced in the temperate regions, its suitable temperatures are in the range between 18 and 25 and it is also tolerant to high temperatures for some extent (Nakwilai *et al*., 2020). Therefore, Japonica rice can be grown successfully in the high altitude areas in the tropics. However, production of Japonica rice in the low altitude areas of the tropics might be possible trough selection for heat tolerance and breeding. Avoiding heat stress in the hot summer might be a successful strategy to produce Japonica rice in the low altitude areas in the tropics. According to Palawisut *et al*. (1995), Japonica rice planted in mid-January had a lower spikelet number per square meter and 1,000-grains weight than the crop planted in mid-November. Climate change with higher temperature could reduce grain yield and grain quality of Japonica rice due to the incomplete development of pollen grains, resulting in the inability of ovary to develop into filled grains. Weather condition is the most important factors affecting growth and yield of Japonica rice (Warinrak, 2013; Sakata *et al*., 2000; Wu *et al*., 2016). However, DOA1 and DOA2 can be grown successfully both rainy and dry seasons in Thailand (Nakwilai *et al*., 2020).

In this study, the crop was transplanted in late January, when the temperatures were low. The temperatures increased with time and were highest at flowering stage (early April). After flowering stage, the temperatures reduced until harvest. High temperature at flowering might increase percentage of unfilled grains and reduced harvest index. Different phenophases of rice markedly varied with not only dates of transplanting but also different weather variables which ultimately create the different crop growing environment to harvest the yield accordingly (Nishad *et al*., 2018). This is possibly due to pollen sterility caused by high temperature during flowering, and high temperature during vegetative phase also reduced grain filling duration, resulting in low harvest index. In this study, percentages of unfilled grains of two varieties were recorded at 49.74 for DOA1 and 33.48 for DOA2, and harvest indexes were recorded at 0.22 for DOA1 and 0.30 for DOA2.

In previous studies, the ranges of harvest indexes in three Indica rice varieties were recorded from 0.50 to 0.53 and the differences in harvest indexes were caused by the differences in percentages of unfilled grains (Puteh *et al*., 2014). The authors suggested that high percentage of unfilled grains in rice was the result of poor translocation and partitioning of assimilates into grains (sink) rather than of limited biomass production or source limitation. According to Laza *et al*. (2003), grain yield was highly associated with harvest index (HI) with an r^2 of 0.73-0.84 in both seasons, and the relationship between grain yield and biomass production was relatively weak.

The increasing trend in yield of cultivars released before 1980 was mainly due to the improvement in harvest index (HI), while an increase in total biomass was associated with yield trends for cultivar lines developed after 1980. Results suggest that further increases in rice yield potential will likely occur through increasing biomass production rather than increasing HI (Peng *et al*., 2000). Ullah *et al*. (2016) found that filled grains per panicle of rice treated with different nitrogen sources ranged between 63.2 and 105.1 grains, whereas unfilled grains ranged between 5.5 and 19.2 grains. Although direct comparison is not possible because the authors used different unit, these data showed that their results of unfilled grains were lower than the results in this study, indicating that two Japonica rice varieties in this study were greatly affected by heat stress. Heat stress was, therefore, an important factor limiting yield of Japonica rice in this study. The interactions between rice variety and fertilizer were not significant for all characters under study. The results suggested that DOA1 and DOA2 responded to different methods of fertilizer application in similar patterns for all parameters.

In conclusion, this study investigated the effects of chemical fertilizer and chicken manure for both single fertilizers and combination fertilizer on growth and yield of two Japonica rice in the hot season in Central Plain, Thailand. Application of chemical fertilizer resulted in greater growth and yield of Japonica rice. Application of chicken manure was better than control for growth and yield, but application of chemical fertilizer in combination with chicken manure had lower growth and yield than control. Chicken manure can be applied to Japonica rice as an alternative organic fertilizer source for Japonica rice production. Two Japonica rice varieties were similar for grain yield. However, they were different in growth characters and yield components. DOA1 grew better and had higher biomass and crop growth rate, whereas DOA2 had higher percentage of filled grains and harvest index. Further investigations in larger scales and under field conditions under different planting dates are still required to find the best planting dates for Japonica rice production in the Central Plain region of Thailand.

Acknowledgements

The authors acknowledge the Chiang Rai Rice Research Center for donation of rice seed.

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(Received: 9 September 2021, accepted: 25 December 2021)