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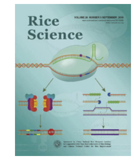

Research Paper

Effects of Integrated Organic and Inorganic Fertilizers on Yield and Growth Parameters of Rice Varieties

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Abstract: We investigated the effects of integrated organic and inorganic fertilizers on the growth and yield of *indica* rice variety Manawthukha and *japonica* rice variety Genkitsukushi. In a split-plot design, the two rice varieties were assigned as main plot factors, and the integrated treatments were the subplot factors, including no-N fertilizer (N_0), 50% chemical fertilizer (CF) (CF_{50}), 100% CF (CF_{100}), 50% CF + 50% poultry manure (PM) ($CF_{50}PM_{50}$), 50% CF + 50% cow manure (CM) ($CF_{50}CM_{50}$), and 50% CF + 50% compost (CP) ($CF_{50}CP_{50}$). CF_{100} was equivalent to N at 85 kg/hm^2. Manure was applied based on the estimated mineralizable nitrogen (EMN) level, which is dependent on total N (%) of each manure type. Manawthukha rice plants were taller with higher tiller number and dry matter content. However, higher soil-plant analysis development (SPAD) values were measured in Genkitsukushi throughout the crop growth period, resulting in higher seed-setting rate (%) and greater yield. At the same N level, $CF_{50}PM_{50}$ application in both rice varieties resulted in higher SPAD values, plant height and tiller number than CF_{100}. $CF_{50}PM_{50}$ containing total N more than 4% supplied synchronized N for the demands of the rice plants, resulting in maximum dry matter, yield and yield components. $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ treatments containing total N less than 4% resulted in lower yields which were similar to CF_{100}. These results indicated that integrating organic and inorganic fertilizers enhanced growth parameters and yields of Manawthukha and Genkitsukushi, while reducing the dose of chemical fertilizer.

Key words: estimated mineralizable nitrogen; growth parameter; inorganic fertilizer; organic manure; rice; yield

Rice (*Oryza sativa* L.) is an important staple food for billions of people. To assure food security in the rice-consuming countries of the world, farmers must produce more rice of better quality to meet the demands of consumers in coming years (Peng and Yang, 2003). However, the average yield of rice has been stagnant and remained lower than the production potential, which might be due to imbalanced use of fertilizers. Excessive or inappropriate use of chemical fertilizers (CFs) is a major cause of nutrient imbalance in soil, leading to high losses, particularly of N from the fertilizer, low N recovery (30%) (Krupnik et al, 2004) and low N use efficiency (about 35%) (Cao et al, 2013) in rice.

Nutrients supplied exclusively through CFs enhance the yield of rice initially, but the yields are not sustainable over time. Imbalanced use of CFs decreases soil fertility and reduces 38% of grain yield in rice (Singh et al, 2001). Thus, there has been a growing interest in the use of organic fertilizers as a source of nutrients. Similar to CFs, organic fertilizers such as poultry manure (PM) mainly contain nitrogenous

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compounds, which are readily mineralized to ammonia and nitrate (Eghball et al, 2002). Cow manure (CM), an important nutrient source for crop production, is rich in N content and recognized as a substitute for inorganic fertilizer (Sharma and Mitra, 1991). In Japan, compost (CP), made from bamboo powder, has become popular. CP has great potential in rice cultivation, where it can serve as a soil fertilizer to supply nutrients for uptake by plants (Binh and Shima, 2018). Nutrient-rich organic manures are an effective substitute to reduce the costs of CFs (Masarirambi et al, 2012).

Excessive application of organic manure should be avoided, particularly in soil, to reduce the risk of toxic effects from reduced metabolic intermediates (Liang et al, 2003). In fact, organic manure alone might not meet the plant's requirements due to the relatively low nutrient contents and the slow release of plant nutrients (Miah, 1994). The integrated use of chemical and organic fertilizers improves plant growth and increases rice yield and quality (Masarirambi et al, 2012).

Many previous studies have focused on applying manure on a weight basis to rice (Hasanuzzaman et al, 2010; Arif et al, 2014; Zhang et al, 2018). However, they have typically neglected the total nutrient (NPK) composition or mineralization of the manure. In fact, a portion of organic N is converted to NH_4-N by soil microbes after application, and NH_4-N is nitrified to nitrate by other soil microbes. Plants can use only mineralized nutrients. One of the major challenges when using manure becomes predicting the amount of mineralizable N that will be derived from organic N in manure for both current and future growing seasons. N released from manure is essential to meet the crop N demand. Some researchers have detected mineralizable N in manure using an incubation test or an analytical method (John et al, 2000; Whitmore 2007; Gil et al, 2011). However, these techniques require special skills, and they are costly and time-consuming. In addition, the proportion of mineralized N from manure during an aerobic incubation test varies widely, ranging from 0% to 50% of the mineralization rate (Kirchmann and Lundvall, 1993). Nishio (2007) determined that the mineralization percentage of manure mainly depends on the total N content of the manure. In the present study, we applied N from PM, CM and CP using estimated mineralizable N (EMN) depending on the total N content of each type of manure according to Nishio (2007). The EMN from the added PM, CM and CP may assist to determine the amount of N fertilizer needed for an enhanced crop yield while decreasing the adverse impacts of excessive CF on the environment. Importantly, no study has applied manure based on EMN integrated with CF in rice.

MATERIALS AND METHODS

Experimental site and rice materials

A field experiment was conducted at Kyushu University farm in Fukuoka Prefecture, Japan (33º37′ N, 130º25′ E) from June to October in 2017 to investigate the effects of integrated organic and inorganic fertilizers on growth parameters, yield and yield components of Manawthukha (*Oryza sativa* subsp. *indica*), a high-yielding Myanmar variety, and Genkitsukushi (*Oryza sativa* subsp. *japonica*), a heat tolerant and high-yielding Japanese variety.

Experimental design and treatments

A split-plot design was laid out with three replications. The two rice varieties were cultivated as main plot factors. The land was irrigated for ease of plowing, then harrowed and divided into two parts (as the main plot area). A plastic lining was inserted at a depth of 15 cm to form the main plots and sub-plots to prevent seepage between adjacent plots. A large plastic liner was installed between the replicates.

Then, the six plots were divided into subplots as replication of the main plots. Six treatments were used, including the control (N_0, no N fertilizer), 50% CF (CF_{50}), 100% CF (CF_{100}), 50% CF + 50% poultry manure: Keifun PM ($CF_{50}PM_{50}$), 50% CF + 50% cow manure: Gyufun CM ($CF_{50}CM_{50}$) and 50% CF + 50% bamboo powder-compost (CP) ($CF_{50}CP_{50}$). CF_{100} was equivalent to 85 kg/hm^2 as urea. In this study, we mainly focused on N application from CF, PM, CM or CP. P and K levels in the manure types were not adjusted. P (as superphosphate) and K (as potash muriate, KCl) were applied at a rate of 60 kg/hm^2 and 85 kg/hm^2 for the CF_{100} application, respectively. The individual plot size was 4.5 m × 1.0 m. The inorganic fertilizer urea and potash muriate were applied as three splits: 60% was incorporated into the soil before the seedlings were transplanted, 20% was applied at the active tillering stage, and the remaining 20% was applied at the panicle initiation stage. The full amount of superphosphate was applied as a basal treatment.

The organic manures PM, CM and CP were basally incorporated into the soil in the respective subplots. The quantity of N applied from PM, CM and CP was calculated as EMN based on total N (%) of each manure type according to Nishio (2007).

Soil and organic manure analyses

The initial soil samples were collected using a soil sampling tube (5 cm in diameter) in nine locations in the experimental field at depths of 0–15 cm prior to the field experiment (Table 1). These soil samples were air-dried at room temperature, crushed by hand, and sieved through a 2-mm-mesh sieve. The air-dried soil samples were analyzed to establish their physical and chemical properties.

Soil pH was measured using a pH meter (pH Meter HM-10P, DKK-TOA Corp., Tokyo, Japan). The samples were digested using the salicylic acid-H_2SO_4-hydrogen peroxide digestion method to analyze total N and P of the soil and manure (Ohyama et al, 1991). Total N was analyzed using the indophenol method (Cataldo et al, 1974), and total P was analyzed by the ascorbic acid method (Murphy and Riley, 1962). Total K, Ca and Mg in the different manures (Table 2) were analyzed using a digesting solution and an atomic absorption spectrophotometer (Z-5300, Hitachi, Tokyo, Japan). In addition, available N (NH_4-N and NO_3-N) and Na of all of the manures were extracted using the hot water extraction method (Curtin et al, 2006). Cation exchange capacity and exchangeable cations in the soil were determined using an ammonium acetate shaking extraction method (Muramoto et al, 1992) followed by atomic absorption spectrophotometry (Z-5300, Hitachi, Tokyo, Japan). The analysis of mineralizable N was performed using the soil incubation method (Sahrawat, 1983) followed by the indophenol method (Cataldo et al, 1974). The available P of soil samples was analyzed using Truog's method (Truog, 1930) followed by the ascorbic acid method (Murphy and Riley, 1962).

Crop management

Good seeds were chosen with a wind blower machine, and sterilized by shaking in 10% ethanol at 150 r/min for 3 min. Then, the seeds were washed at least three times in distilled water, and shaken again in 5% NaClO solution at 150 r/min for 30 min. The sterilized seeds were washed in distilled water and stored in a 25 ºC incubator for 48 h in the dark.

Table 1. Physical and chemical properties of surface (0–15 cm) profile of soil.

Physicochemical property	Value
Soil pH (soil/H_2O 1.0:2.5)	6.12
Soil pH (soil/KCl 1.0:2.5)	4.82
EC (soil/H_2O 1:5) (mS/m)	9.42
Total N (%)	0.15
Mineralizable N (g/kg)	5.20
Total P_2O_5 (%)	0.25
Available P (g/kg)	15.37
Total K_2O (%)	0.48
Cation exchangeable capacity (cmol/kg)	15.70
Exchangeable Ca (cmol/kg)	7.18
Exchangeable Mg (cmol/kg)	1.62
Exchangeable K (cmol/kg)	0.37
Exchangeable Na (cmol/kg)	0.75

The incubated seeds were homogenously sown on seedbeds (100 g) using commercial seedbed soil (Kokuryu Baido, Seisin Sangyo Co., Kitakyushu, Japan). On June 22, 2017, the 21-day-old seedlings were transplanted to 25 cm × 15 cm hill with two seedlings per hill. Irrigation was conducted as common management together with the surrounding area. The Manawthukha plants were harvested when the crops reached maturity at 122 d after transplanting (DAT) (October 23, 2017). Because Genkitsukushi rice has a shorter growth period, the plants were harvested at 94 DAT (September 25, 2017).

Plant growth characteristics

Five hills from each plot were marked to determine plant height (cm), number of tillers per hill and soil-plant analysis development (SPAD) values. Growth characteristics were measured weekly from 10 DAT to 50% flowering and at 2-week intervals after flowering. The SPAD values were measured using a SPAD-502 chlorophyll meter (Konica Minolta, Inc., Osaka, Japan). The uppermost fully expanded leaf was used to measure the SPAD value before the panicle initiation stage, and the flag leaf was used thereafter.

Plant sampling and determination of dry matter, yield and yield components

At the active tillering, panicle initiation and flowering

Table 2. Chemical compositions of poultry manure, cow manure and compost. %

Sample	Ash content	Moisture	Total N	NH_4-N	NO_3-N	P_2O_5	K_2O	Ca	Mg	Na
Poultry manure	37.37	21.86	4.87	0.75	0.00	4.56	2.14	8.85	0.75	0.28
Cow manure	31.48	46.40	2.39	0.19	0.00	1.91	1.52	1.09	0.55	0.34
Compost	28.13	41.02	2.16	0.04	0.02	2.27	1.18	5.28	0.21	0.85

stages, two hills from each plot were cut (2–3 cm above the ground). The samples were oven-dried at 70 ºC for 48 h and then weighed immediately. Dry matter (DM) accumulation is expressed as tons per hectare (t/hm^2).

At harvest time, ten hills were used to measure DM, yield and yield components, such as number of panicles per hill, number of spikelets per panicle, seed-setting rate (%), 1000-grain weight (g) and maximum panicle length (cm). Harvest index (HI) was calculated as the ratio of economic yield (seed weight) to biological yield (total DM weight) (Yoshida, 1981).

Statistical analysis

The data were subjected to analysis of variance. The comparison of treatment means was performed using Tukey's honestly significant difference test at 5% level using Statistix software (ver. 8.0; Analytical Software, Tallahassee, FL, USA).

RESULTS

Plant growth characteristics

Plant height of Manawthukha was superior to that of Genkitsukushi throughout the crop growing period (P < 0.05) (Fig. 1-A and -B). In both rice varieties, $CF_{50}PM_{50}$ treatment provided taller plants at all the growth stages. Maximum plant height was attained at harvest (109.76 cm in Manawthukha and 102.49 cm in Genkitsukushi). Plant heights in $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ treatments were the same as those in CF_{100} in both varieties.

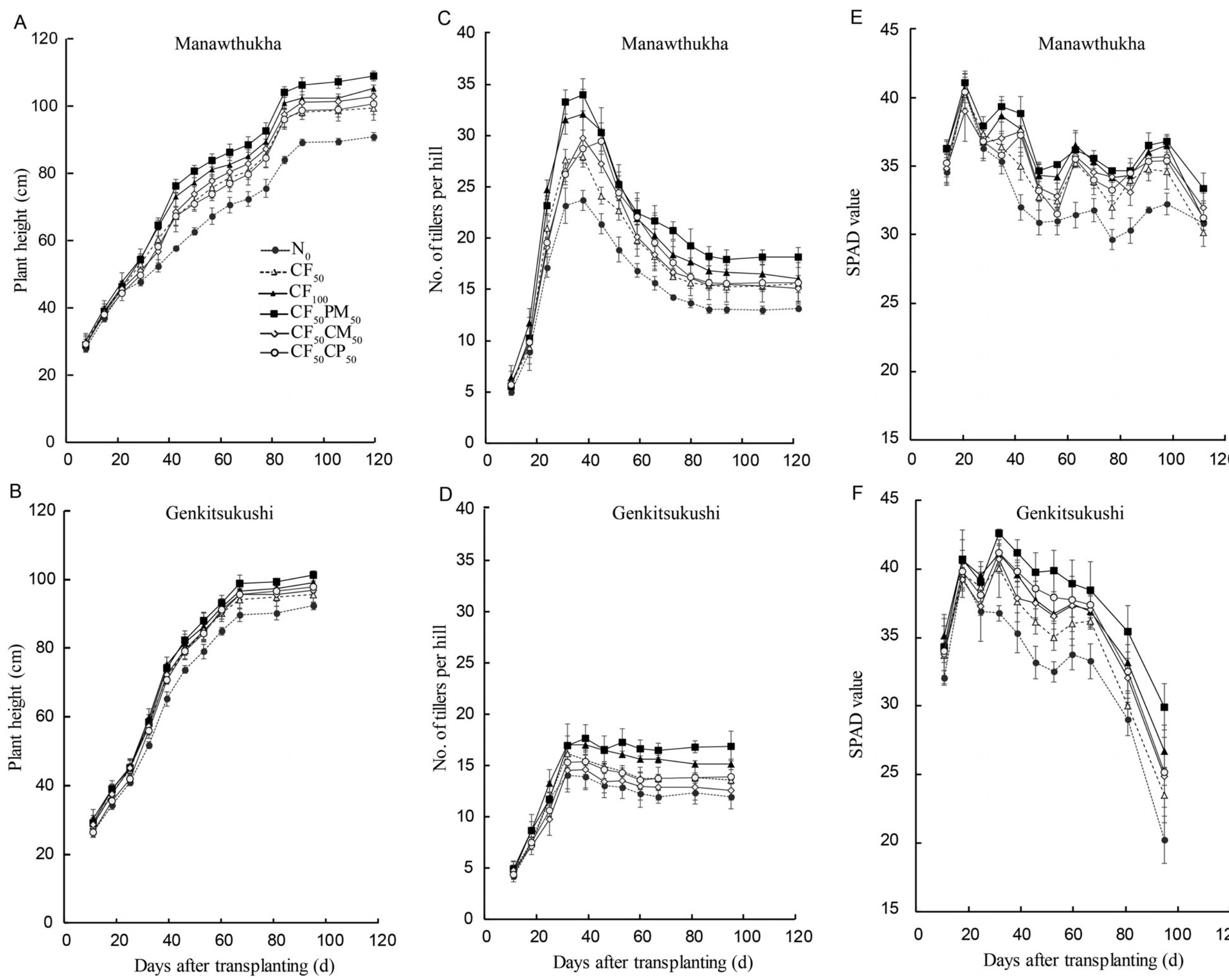

Fig. 1. Plant height, tiller number and changes in soil-plant analysis development (SPAD) value of Manawthukha (A, C and E) and Genkitsukushi (B, D and F) affected by integrated organic and inorganic fertilizers.

N_0, No-N fertilizer; CF_{50}, 50% chemical fertilizer (CF); CF_{100}, 100% CF; $CF_{50}PM_{50}$, 50% CF + 50% poultry manure (PM); $CF_{50}CM_{50}$, 50% CF + 50% cow manure (CM); $CF_{50}CP_{50}$, 50% CF + 50% compost (CP). CF, Chemical fertilizer; PM, Poultry manure; CM, Cow manure; CP, Compost.

Error bar represents standard deviation (n = 3).

The two varieties had quite different tillering patterns (Fig. 1-C and -D). Manawthukha had a higher tillering capacity, and the maximum tiller number reached the peak (35 tillers) quickly at 35 DAT. After 40 DAT, the tiller number decreased in all the treatments until the panicle initiation stage. At the same time, the number of Genkitsukushi tillers steadily increased to the maximum number (18 tillers) at 30 DAT. After that stage, a slight decrease in tiller number was found in the integrated treatments, except $CF_{50}PM_{50}$. At harvest, $CF_{50}PM_{50}$ treatment produced the maximum number of tillers (18.2 in Manawthukha and 16.8 in Genkitsukushi) (P < 0.05). No significant difference in the number of tillers was observed among CF_{100}, $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ treatments.

Similar SPAD values were recorded among the integrated treatments before the active tillering stage, but they differed at later stages (P < 0.05) (Fig. 1-E and -F). The SPAD values of Genkitsukushi were significantly higher than those of Manawthukha throughout the growing period. $CF_{50}PM_{50}$ treatment produced the highest SPAD values at all developmental stages in both varieties. $CF_{50}CM_{50}$- and $CF_{50}CP_{50}$-treated plots had lower SPAD values, which were similar to the CF_{100}-treated plots.

CF_{100} treatment in both varieties provided maximum DM at the active tillering stage (P < 0.01) (Fig. 2). After this developmental stage, DM of CF_{100} showed

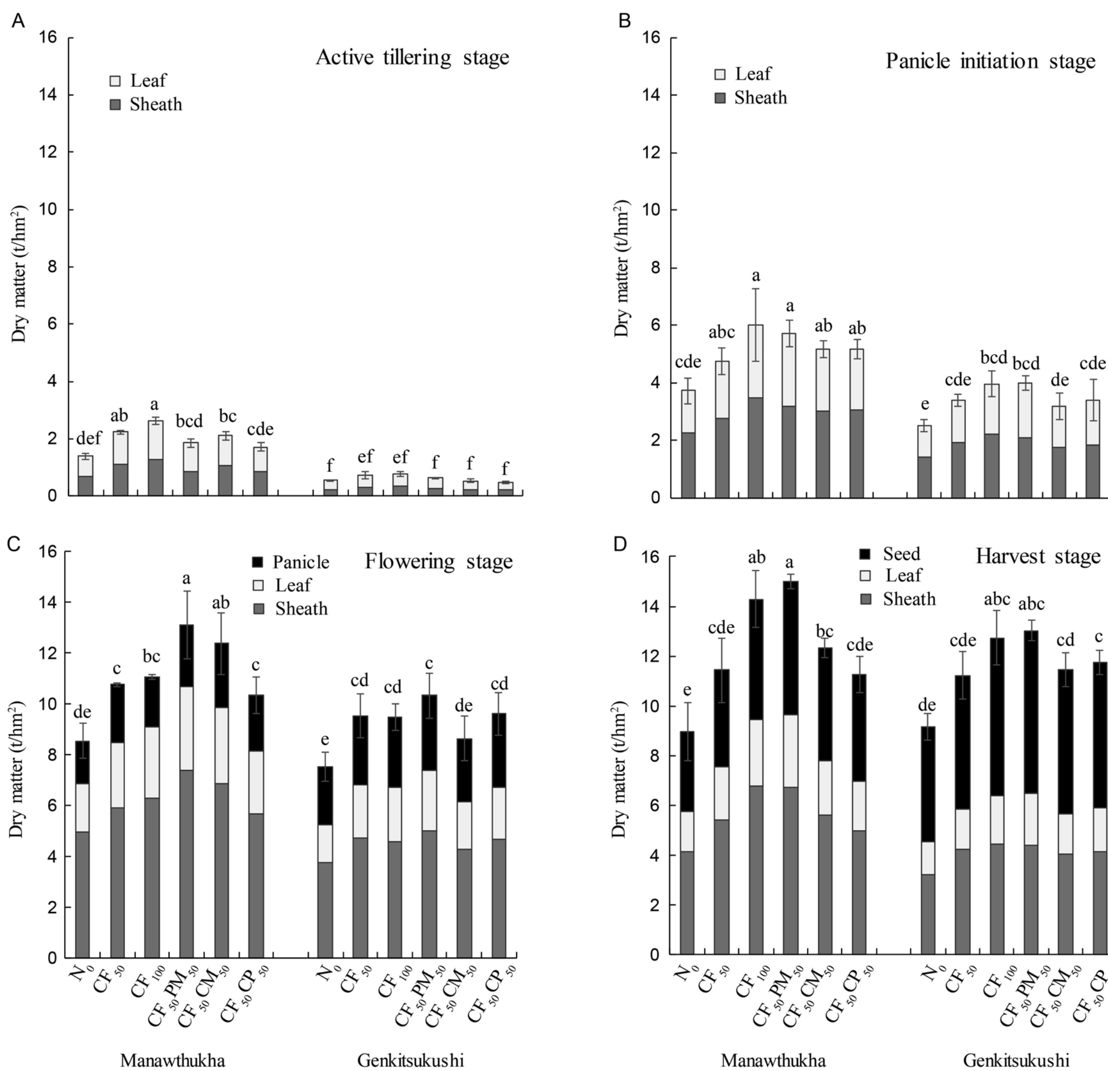

Fig. 2. Interaction effects of variety and integrated fertilization on dry matter of rice varieties at the critical growth stages.

N_0, No-N fertilizer; CF_{50}, 50% chemical fertilizer (CF); CF_{100}, 100% CF; $CF_{50}PM_{50}$, 50% CF + 50% poultry manure (PM); $CF_{50}CM_{50}$, 50% CF + 50% cow manure (CM); $CF_{50}CP_{50}$, 50% CF + 50% compost (CP).

Error bar represents standard deviation (n = 3). The histograms with the same letter at each growth stage are not significantly different by the Tukey's honestly significant difference test (P < 0.05).

Table 3. Harvest index, yield and yield components of rice affected by integrated organic and inorganic fertilizers.

Treatment	Harvest index	No. panicle per hill	No. spikelets per panicle	Seed-setting rate (%)	1000-grain weight (g)	Maximum panicle length (cm)	Yield (t/hm^2)
Variety (V)							
Manawthukha (*indica*)	0.48 ± 0.66 b	15.39 ± 0.77 a	96.88 ± 7.10 a	73.48 ± 5.87 b	19.57 ± 1.04 b	23.07 ± 1.67 a	5.48 ± 0.21 b
Genkitsukushi (*japonica*)	0.58 ± 0.02 a	13.53 ± 0.29 b	76.65 ± 3.79 b	78.13 ± 3.05 a	27.25 ± 0.78 a	20.92 ± 1.11 b	6.71 ± 0.86 a
Tukey $HSD_{0.05}$	0.05	1.33	17.89	0.70	2.28	1.16	0.32
Integrated fertilization (F)							
N_0	0.49 ± 0.07 ab	12.58 ± 0.50 c	68.24 ± 7.90 b	70.25 ± 2.01 c	24.54 ± 2.01 a	17.05 ± 5.65 b	4.66 ± 0.20 c
CF_{50}	0.43 ± 0.03 b	13.50 ± 0.76 c	71.46 ± 7.10 b	72.86 ± 5.80 b	23.69 ± 0.12 a	22.50 ± 1.74 a	5.19 ± 0.73 bc
CF_{100}	0.51 ± 0.05 a	16.08 ± 0.51 ab	91.11 ± 6.34 a	79.75 ± 3.88 a	23.15 ± 0.52 a	23.07 ± 0.80 a	6.80 ± 0.88 a
$CF_{50}PM_{50}$	0.54 ± 0.04 a	16.68 ± 0.53 a	99.49 ± 2.24 a	82.08 ± 5.40 a	23.36 ± 1.04 a	23.57 ± 0.64 a	7.42 ± 0.23 a
$CF_{50}CM_{50}$	0.55 ± 0.06 a	14.08 ± 0.29 bc	96.88 ± 3.77 a	75.27 ± 4.71 b	22.97 ± 0.99 a	22.72 ± 0.45 a	6.47 ± 0.31 ab
$CF_{50}CP_{50}$	0.52 ± 0.02 a	13.83 ± 0.57 bc	93.45 ± 8.04 a	74.61 ± 3.22 b	22.75 ± 0.77 a	23.07 ± 0.72 a	6.03 ± 1.04 abc
Tukey $HSD_{0.05}$	0.07	2.53	14.97	2.53	1.87	3.40	1.47
V	0.0070	0.0265	0.0397	0.0012	0.0047	0.0154	0.0038
F	0.0005	0.0004	< 0.0001	< 0.0001	0.0809	0.0001	0.0001
V × F	0.0389	0.9820	< 0.0001	0.0001	0.0494	0.0528	0.0034
CV (%)	8.27	9.65	9.51	10.85	4.40	8.54	13.31

N_0, No-N fertilizer; CF_{50}, 50% chemical fertilizer (CF); CF_{100}, 100% CF; $CF_{50}PM_{50}$, 50% CF + 50% poultry manure (PM); $CF_{50}CM_{50}$, 50% CF + 50% cow manure (CM); $CF_{50}CP_{50}$, 50% CF + 50% compost (CP).

Values are Mean ± SD (n = 6), followed by the same letter in the same case in each column are not significantly different in Tukey's honestly significant difference test (P < 0.05).

no difference from those of $CF_{50}PM_{50}$, $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ in either variety. Manawthukha realized a greater DM at harvest time than Genkitsukushi in all the treatments. $CF_{50}PM_{50}$ treatment achieved the highest DM (15.00 t/hm^2 in Manawthukha and 13.02 t/hm^2 in Genkitsukushi). In both varieties, DM of CF_{100} was lower than that of $CF_{50}PM_{50}$ but similar to those of $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ at the time of harvest.

Harvest index, yield, and yield parameters

HI ranged from 0.33 to 0.49 in Manawthukha and from 0.52 to 0.61 in Genkitsukushi (Table 3). Manawthukha produced more panicles per hill than Genkitsukushi (P < 0.05) (Table 3). In the integrated treatments, $CF_{50}PM_{50}$ plots produced the highest value. A similar value (16.08) was recorded by CF_{100} treatment. Plants in $CF_{50}CM_{50}$, $CF_{50}CP_{50}$ and CF_{50} treatments produced 14.08, 13.83 and 13.50 panicles per hill, respectively.

Manawthukha produced a significantly higher number of spikelets per panicle than Genkitsukushi (Table 3). $CF_{50}PM_{50}$ treatment recorded the maximum number (P < 0.01). However, similar numbers of spikelets were observed in CF_{100}, $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ treatments. A strong interaction effect was detected between varieties and integrated fertilization treatments in terms of spikelet number per panicle. Genkitsukushi achieved the highest seed-setting rate (Table 3). Among the integrated treatments, the highest seed-setting rate was produced by $CF_{50}PM_{50}$ treatment, which was similar to that by CF_{100}. Seed-setting rates of $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ were 75.27% and 74.61%, respectively, relatively lower than that of CF_{100}.

1000-grain weight was unaffected by the integrated organic and inorganic fertilizer treatments but was affected by the rice variety (Table 3). Genkitsukushi produced a higher 1000-grain weight (27.25 g) than Manawthukha (19.57 g). The panicle of Manawthukha was significantly longer than that of Genkitsukushi (P < 0.05) (Table 3). Panicle length was not significantly affected by the integrated treatments. Nonetheless, $CF_{50}PM_{50}$ treatment produced the longest panicles (23.57 cm).

Genkitsukushi obtained higher yield compared with Manawthukha (P < 0.01) (Table 3). N supply of $CF_{50}PM_{50}$ treatment was well synchronized with crop N demand throughout the crop growing period, resulting in the highest yield (7.42 t/hm^2). $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ treatments resulted in lower yields (6.47 and 6.03 t/hm^2, respectively), with similar to CF_{100} (6.80 t/hm^2). CF_{50} treatment plots produced a lower yield of 5.19 t/hm^2, but this was still higher than the N_0 plots (4.66 t/hm^2).

An interaction effect was detected between variety and the integrated treatments on rice yield (P < 0.01) (Table 3 and Fig. 3). $CF_{50}PM_{50}$ treatment resulted in the highest yield of Manawthukha at 6.90 t/hm^2 (Fig. 3). $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ treatments produced lower yields, 5.87 and 5.51 t/hm^2, respectively, but these were similar to CF_{100} (6.30 t/hm^2). Similarly, $CF_{50}PM_{50}$ treatment produced the highest yield (7.93 t/hm^2) in Genkitsukushi, followed by CF_{100} (7.32 t/hm^2), $CF_{50}CM_{50}$ (7.06 t/hm^2) and $CF_{50}CP_{50}$ (6.55 t/hm^2).

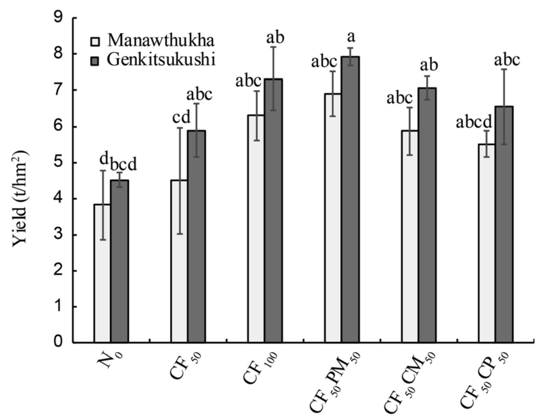

Fig. 3. Interaction effect of variety and integrated fertilization on rice yield.

N_0, No N fertilizer; CF_{50}, 50% chemical fertilizer (CF); CF_{100}, 100% CF; $CF_{50}PM_{50}$, 50% CF + 50% poultry manure (PM); $CF_{50}CM_{50}$, 50% CF + 50% cow manure (CM); $CF_{50}CP_{50}$, 50% CF + 50% compost (CP).

Error bar represents standard deviation (n = 3). The histograms with the same letter are not significantly different by the Tukey's honestly significant difference test ($P < 0.05$).

However, CF_{50} and N_0 plots did not produce optimum yields in either rice variety.

DISCUSSION

In this study, we cultivated *indica* rice variety Manawthukha and *japonica* rice variety Genkitsukushi. Nutrient absorption characteristics generally vary with the rice cultivar, fertilizer type, fertilizer technology, soil type, and environmental factors (Huang et al, 2008). We also studied the different responses to manure application (i.e., EMN) in the rice varieties.

Beneficial effect of integrated organic and inorganic fertilizer

Many previous studies have reported that applying CF alone causes high nutrient loss, particularly N loss. Several methods have been used to alleviate N loss after applying CF, including applying N at a later growth stage (Peng et al, 2010), adjusting the N rate based on chlorophyll readings (Hu et al, 2007), applying controlled-release N fertilizer (Yang et al, 2012), using urease inhibitors (Chao et al, 2005) and planting highly efficient rice varieties (Zhu et al, 2016). However, the use of CF integrated with manure is a simple, inexpensive method that is readily available to farmers. Many researchers have recommended manure application rates to farmers, such as PM of 5 t/hm^2 (Biswas et al, 2016), CM of 10 t/hm^2 (Sudarsono et al, 2014) and CP of 10 t/hm^2 (Hussain et al, 2001). The nutrient supply from organic manure can be excessive or insufficient for rice growth and unsynchronized with crop N demands. We applied PM, CM and CP based on EMN depending on their total N content according to Nishio (2007). We reduced the amount of CF to 50% of the recommended rate without decreasing the growth parameters or yields of either rice variety using organic manure (i.e., EMN) and CF. Therefore, the integrated 50% EMN with PM, CM or CP and 50% of the recommended CF was effective in terms of growth parameters and yields in Manawthukha and Genkitsukushi, compared with CF_{100} alone.

Growth parameters and yields of rice affected by CF, PM, CM and CP

Basal CF has traditionally been broadcast or mixed in a shallow soil layer by rice farmers. This approach enhances NH_4-N content in the surface soil layer and flood waters (Garnett et al, 2009). It is not necessary to maintain a high N concentration in the top soil layer during the early growth stage because the rice root is too small and plant N demand is low (Liu et al, 2016). However, N that is not absorbed by young rice plants may be lost. As the plants grow, their nutrient requirements increase, while the N concentration in the soil or flooded water gradually decreases. The N supplied by CF is thus not synchronized with the crop N requirement. In this study, the general rate of CF_{100} created this phenomenon. CF_{100} and CF_{50} treatments resulted in higher growth parameters and greater SPAD values until the active tillering stage in both varieties due to high N concentration in flood water or soil. After that stage, growth of both rice varieties in CF_{100} decelerated due to a gradual decrease in the supply of N. Consequently, DMs of CF_{100} were significantly lower than those of the integrated $CF_{50}PM_{50}$ treatment at the later growth stages and at harvest. As a result, yield from CF_{100} treatment was relatively lower than that from $CF_{50}PM_{50}$, but similar to those of $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ in both varieties. Applying CF alone could result in N loss and low N recovery (Liu et al, 2016), which increases the risk of environmental pollution by eutrophication as well as economic losses (Akoumianakis et al, 2011).

The growth parameters of plants that received the integrated treatments were relatively lower than those of CF_{50} and CF_{100} until the active tillering stage because manure releases nutrients slowly under mineralization throughout the crop growing period (Myint et al, 2011). After that stage, the plants from $CF_{50}PM_{50}$ treatment in both varieties produced higher

SPAD values across all the treatments due to a greater mineralizable N supplied from the manure. As a result, taller plants of $CF_{50}PM_{50}$ treatment produced a larger number of tillers, followed by plants of CF_{100}, $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ treatments. PM_{50}, which contained high total N (4.87%) and NH_4-N (0.75%) contents, provided a steady supply of N during all crop growing periods after integration with 50% CF. As a result, higher DM content of $CF_{50}PM_{50}$ treatment was produced in both varieties after the panicle initiation stage than that with CF_{100} alone. Manure with a higher total N has more N readily available for rice plants (Eghball et al, 2002). Although the same EMN rates were applied, CF_{50} + CM_{50} (total N, 2.39%) or CP_{50} (total N, 2.16%) produced lower growth parameters and DM content in both rice varieties, with similar to the DM content with CF_{100}. CM and CP may have lower mineralization of nutrients because they contained less total N than PM. It is well documented that manures with high C/N ratios increase the immobilization process (Barakat et al, 2016) due to slower decomposition and nitrification (Khalil et al, 2005).

A steady supply of nutrients at the panicle initiation and grain filling stages ensures that the plants grown with $CF_{50}PM_{50}$ obtain the highest number of fertile (active) tillers, which produce the panicles. The maximum number of spikelets per panicle was attained by $CF_{50}PM_{50}$ treatment in both varieties. $CF_{50}CM_{50}$ and $CF_{50}CP_{50}$ treatments also resulted in a higher number of spikelets per panicle but resulted in the fewest number of panicles. The numbers of fertile tillers per hill and spikelets per panicle increased significantly when PM was combined with 50% of the recommended amount of CF (Razzaque, 1996; Arif et al, 2014). Kenchaiah (1997) demonstrated that PM treatment enhances physical grain characteristics due to the good supply of N. For that reason, $CF_{50}PM_{50}$ treatment significantly increased the number of filled grains per panicle and maximum panicle length, and obtained the maximum yields of both rice varieties.

Differences in characters between rice varieties

Manawthukha produced higher plants with more tillers. However, a larger number of dead tillers were observed on Manawthukha after the tillering stage, but not on Genkitsukushi. This pattern may be a varietal character of the rice. The higher number of tillers a variety exhibits, the greater the competition between early-emerged and later-emerged tillers for accumulated carbohydrates in the leaf sheath and culm (Nuruzzaman et al, 2000). Manawthukha had a lower percentage of productive tillers and a higher number of dead tillers, whereas Genkitsukushi had a higher percentage of productive tillers.

Manawthukha obtained higher DM content but a lower yield. Consequently, HI was lower in Manawthukha than Genkitsukushi. Vose and Blixt (1984) reported that *japonica* rice varieties enhance grain yields with increased fertilization, and *indica* varieties produce the highest yield within its range but show no response to higher fertility levels. The translocation of nutrients to the grain is more efficient in *japonica* compared to *indica* rice varieties (Yoshida, 1981). Rice varieties are categorized by panicle number type and panicle weight type (Vose and Blixt, 1984). Genkitsukushi achieved the highest yield, as it belongs to the panicle weight type due to heavier individual seed weight compared with Manawthukha.

CONCLUSIONS

In this study, we determined that an integrated application of PM, CM, CP (based on EMN) and CFs was an effective approach to enhance growth, yield and yield components of Manawthukha (*indica*) and Genkitsukushi (*japonica*). CF_{50} (42.5 kg/hm^2) + PM_{50} (42.5 kg/hm^2) treatment showed the best performance in terms of growth parameters and yields of both rice varieties. CM_{50} (42.5 kg/hm^2) may be useful as an effective fertilizer when integrated with CF_{50} (42.5 kg/hm^2) where PM is limited. Furthermore, CP_{50} (42.5 kg/hm^2), which was made from bamboo powder, also showed great potential as a substitute for 50% of CF in Japanese rice cultivation. Therefore, organic manure, such as PM, which contains high total N (> 4%) and moderate P and K, is more compatible with EMN and should be integrated with 50% of the recommended CF not only to improve yield but also to further reduce the amount of CF applied for sustainable agriculture. The results of this study will be useful for enhancing the yields of Manawthukha and Genkitsukushi rice using integrated organic (i.e., EMN) and inorganic fertilizers. Additionally, this study evaluated the effects of this fertilization scheme on growth parameters and dry matter (DM) contents in the two rice varieties.

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