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ARTICLE

Effect of different application levels of rapeseed meal on growth and yield components of rice

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Abstract Application of rapeseed meal as organic fertilizer improves soil environment and crop productivity by supplying the nutrients. This study aimed to investigate the optimal application levels of rapeseed meal for rice cultivation. Application of rapeseed meal increased the height of rice plants by about 5–10% compared to the control, and its application at a rate of 50, 100, 200, and 300 kg/0.1 ha increased the nitrogen content in rice leaves at 30 days after treatment by 107.3, 110.4, 114.7, and 114.7%, respectively, compared to the control. In treatments with a mixture of chemical fertilizer and rapeseed meal (50, 100, 200, and 300 kg/0.1 ha), the nitrogen content in rice leaves increased by 105.1–107.7% compared to that in the control; there was no significant difference between the treatment with chemical fertilizer only and that with the mixture of chemical fertilizer and rapeseed meal. The chemical properties of soil treated with rapeseed meal at 200 and 300 kg/0.1 ha or with the mixture of 200 kg/0.1 ha rapeseed meal and chemical fertilizer (1/2 level) showed that nitrate and ammonium increased in treated soils as compared to untreated soil. The yield and yield components were positively correlated with the application levels of rapeseed meal and the mixture of rapeseed meal and chemical fertilizer. The application of rapeseed meal at 100–200 kg/0.1 ha is considered optimal, and efficient application of nitrogen is achieved by mixing chemical fertilizer (11 kg/0.1 ha) with rapeseed meal (100–200 kg/0.1 ha).

Keywords Nitrogen · Organic fertilizer · Productivity · Rapeseed meal · Rice

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Introduction

Production of rapeseed as a representative oilseed crop worldwide has dramatically increased. Seed and oil production of rapeseed in 2015–2016 was approximately 70 and 27 million ton, respectively (USDA http://usda.mannlib.cornell.edu/usda/fas/oilseed-trade//2010s/2016/oilseed-trade-05-10-2016.pdf FAS). Rapeseed is grown not only for beautiful landscape but also for production of edible oil and as leaf vegetable, feed, and raw material for industries such as cosmetics. By-products of rapeseed processing can also be used as livestock feed and organic fertilizer.

In the past, before the introduction of chemical fertilizers, rice straw, green foliage, night soil, and native wild grasses were used for crops as self-supporting fertilizers. Since the production of chemical fertilizers commenced, fertilizer application rate has rapidly increased for a maximum yield, endangering the production of safe agricultural products and contaminating the soil, rivers, and lakes. Since 1990, the production of eco-friendly agricultural products has steadily increased in developed countries in Europe and North America for food safety and environmental protection [1]. In Korea, a law promoting environment-friendly farming was enacted in

1998, exposing a tendency for environment awareness and quality of quantity-oriented agricultural production. In organic rice cultivation, chemical fertilizers are replaced with organic fertilizers such as green manure and compost to supply nutrients necessary for crop growth. However, crop cultivation methods implementing green manure crops impose limitations to standard cultivation methods used in organic rice cultivation due to problems pertaining to seed supply and demand, optimum decomposition of green manure, and the dependence of green manure crop yield on weather conditions [2, 3]. Therefore, the efficient and economical application of organic fertilizer through resource circulation and utilization of crop by-products is attracting attention. The research on the application of organic fertilizers has been carried out in fields cultivated with rice [2–6], maize [7], ginseng [8], peony [9], *Fritillaria* [10], *Achyranthes* [11], lettuce and garland [12], radish and Chinese cabbage [13, 14], *Ficus benjamina* [15], *Cypripedium macranthum* [16], and apple [17]. Application of organic fertilizer to paddy soils has a significant effect on rice yield depending on carbon and nitrogen content (C/N ratio) in the fertilizer [18, 19], but it is also necessary to confirm the seasonal changes in nitrogen level and organic matter in the fertilizer.

The nitrogen, phosphorus, and potassium contents are the important elements to determine the quality of organic fertilizers and proper level of application for crop cultivation. The major nutrient contents in various organic fertilizers were investigated in previous study [20]. Among them, total N contents in soybean meal, perilla and rapeseed meal showed the high level with >60 g kg^{-1}. Rapeseed meal used as a source of organic matter and other nutrients in environmentally friendly agriculture, including organic farming, has higher nutrient content compared to livestock manure [21], and its application improves soil environment and crop productivity by supplying required nutrients. Since the optimal levels of rapeseed meal applied to soil depend on the type of crops, they should be evaluated for each crop. Therefore, to reduce the use of chemical fertilizers as part of eco-friendly agriculture, the present study aimed to investigate the effects of different application levels of organic fertilizer prepared from rapeseed meal in rice paddies on nitrogen fertilization and rice growth and yield.

Materials and methods

This study was conducted in environmentally friendly rice paddy fields located in Jusan-myeon, Buan-gun, Jeollabuk-do, Republic of Korea, using the rice cultivar High Ami. The organic fertilizer used in the experiment was rapeseed meal; its chemical composition is shown in Table 1. Water content of the rapeseed meal was measured by the oven-drying method, total nitrogen was measured by an C/N analyzer (Variomax CN, Elementar Analysensysteme GmbH, Langenselbold, Germany), and phosphorus, potassium, copper, and zinc ions were analyzed by an ICP-OES Optima 8300 spectrometer (PerkinElmer Inc., Waltham, MA, USA). Rice seedlings were transplanted using a machine transplanting method at a spacing of 30 × 15 cm. As an organic cultivation, application levels of the organic fertilizer (rapeseed meal) were calculated as 0-, 0.25-, 0.5-, 1-, and 1.5-fold (0, 50, 100, 200, 300 kg/0.1 ha) of the recommended doses of *N* (10 kg/0.1 ha) in chemical fertilizers. For treatments with a mixture of chemical fertilizer and rapeseed meal, the application levels were adjusted to 33% of the recommended *N*, *P*, and *K* (10, 4.7, and 6 kg/0.1 ha, respectively) amounts in chemical fertilizers and no rapeseed meal as a control, and 16.5% application level of chemical fertilizer adding rapeseed meals (50, 100, 200, 300 kg/0.1 ha). Each test area was 54 or 18 m^2, and they were arranged in randomized block design (2 repeats). To analyze the total nitrogen content in rice samples, tissues were collected at each growing stage of rice and quantified with the C/N analyzer (Elementar, Germany). Soil pH and electrical conductivity were measured with an Orion Versa Star Pro pH/EC meter (Thermo Fischer Scientific, Waltham, Massachusetts, USA). Total nitrogen content, organic matter, available phosphate, and available silicate in soil were analyzed by Kjeldahl method, Tyurin method, Lancaster method, and by leaching with 1 N–NaOAc (pH 4.0) buffer solution and colorimetry (Cintra 202, Nordantec GmbH, Bremerhaven, Germany), respectively. Exchangeable cations were leached into 1 N–NH_4OAC (pH 7.0) buffer solution and analyzed using an inductively coupled plasma emission spectrometer (ICP-OES, Optima 8300, Perkin Elmer, USA). NO_3–N and NH_4–N were leached into 2 M KCl solution and analyzed by Kjeldahl method. Plant height was measured one month after each treatment to evaluate rice growth, and yield and yield components (dry

Table 1 Chemical properties of rapeseed meal

	Water (%)	OM (%)	T–N (%)	T–P (%)	T–K (%)	Cu (mg/kg)	Zn (mg/kg)	Salinity (%)
Rapeseed meal	6.44	88.03	4.78	2.14	1.13	3.70	56.35	0.03

Data represent the means ($N = 6$). *OM* organic matter, *T–N* total nitrogen, *T–P* total phosphorus, *T–K* total potassium weight, spikelet number per panicle, ripening rate, thousand grain weight, and yield index of rice) were investigated at harvest. The ripening percentage of the rice was estimated by counting the total number of ripened grain except empty heads of grain (chaff), and results were expressed in %. Ripening percentage is calculated by the following equation: (A–B)/A × 100, where *A* is the total number of grains and *B* is the number of chaff. Yield index was determined by the following equation: weight of grain was harvested in each plot/weight of grain was harvested in control plot ×100. At maturity, 1.0 m^2 of rice plants in each plot was harvested. We performed statistical analyses using the SPSS statistical software (SPSS, Chicago, IL, USA). All biological data were analyzed by the Turkey test after one-way ANOVA. Statistical differences among data for different results were considered statistically significant at $P < 0.05$.

Results and discussion

Chemical analysis of the rapeseed meal revealed that organic matter comprised the major component, followed by nitrogen (4.78%), phosphoric acid (2.14%), and potassium (1.13%) (Table 1). These results were similar to the chemical composition of rapeseed meal reported in various organic fertilizers [20].

Rice plants were about 5–10% taller in treatments with rapeseed meal than in treatments with no fertilizer application (Fig. 1); the difference was greater in treatments with a mixture of rapeseed meal and chemical fertilizer (Fig. 2). Oilseed meal produces more available nitrogen ions when decomposed under flooding, and when mixed with soil, it decomposes faster, releasing nutrients required for plant growth [22]. The nitrogen content in leaves measured at 30 days after treatments with 50, 100, 200, and 300 kg/0.1 ha of rapeseed meal increased by 107.3, 110.4, 114.7, and 114.7%, respectively (Fig. 3). The nitrogen content of rice leaves in treatments with a mixture of chemical fertilizer and rapeseed meal increased at all rates of application, whereas in treatments with rapeseed meal (50, 100, 200, 300 kg/0.1 ha) and chemical fertilizer (1/2 level), the levels were similar to the nitrogen content of leaves in treatments with chemical fertilizer alone (Fig. 4). At the panicle formation stage, nitrogen content in panicle increased in treatments with 100 kg or more rapeseed meal per 0.1 ha, whereas that in treatments with the mixture of 100–300 kg/0.1 ha of rapeseed meal and chemical fertilizer (1/2 level) was similar to the nitrogen content in the panicle of rice plants supplemented with chemical fertilizer only (Fig. 5). At the harvest stage, nitrogen content in the grain was higher in all treatments compared to that in untreated rice grain (Fig. 6).

We investigated the chemical properties of soil supplemented with 200 kg/0.1 ha or 300 kg/0.1 ha of rapeseed meal or with the mixture of 200 kg/0.1 ha of rapeseed meal and chemical fertilizer (1/2 level). The results showed that the nitrate and ammonium content, as sources of inorganic nitrogen, tended to increase in all these treatments compared to untreated soil (Table 2). The mixture of rapeseed meal and chemical fertilizer (200 + 11.1 kg/0.1 ha) contains 116.5% of recommended nitrogen content, and rapeseed meal alone (300 kg/0.1 ha) contains 150% of the nitrogen content. However, higher contents of nitrogen remain in the soil treated with the mixture of rapeseed meal and chemical fertilizer. Perhaps, it was presumed that nitrogen uptake rate of rice plant was lower nitrogen uptake rate versus nitrogen input in the soil treated with the mixture of rapeseed meal and chemical fertilizer compared with rapeseed meal alone treatment.

Finally, we investigated the dry weight, spikelet number per panicle, ripening rate, thousand grain weight, and yield index of rice at harvest in correlation with the application

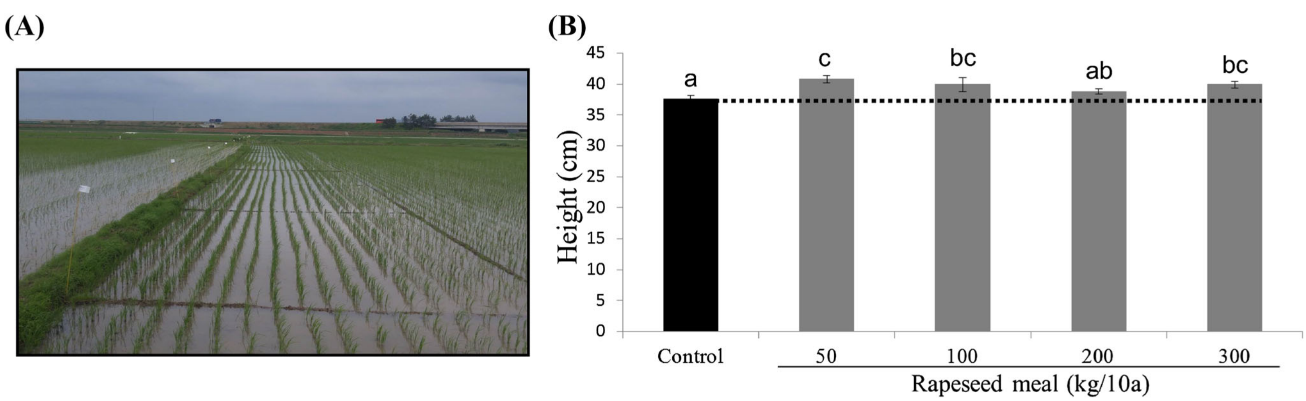


Fig. 1 Rice plants grown on a paddy soil supplemented with 0, 50, 100, 200, and 300 kg/0.1 ha rapeseed meal (**A**) and the effect of rapeseed meal treatments on plant height at 30 days after treatment (**B**). Data represent mean ± standard error ($n = 10$). Different lowercase letters in the figure indicate significant difference at $P < 0.05$ by Tukey's test

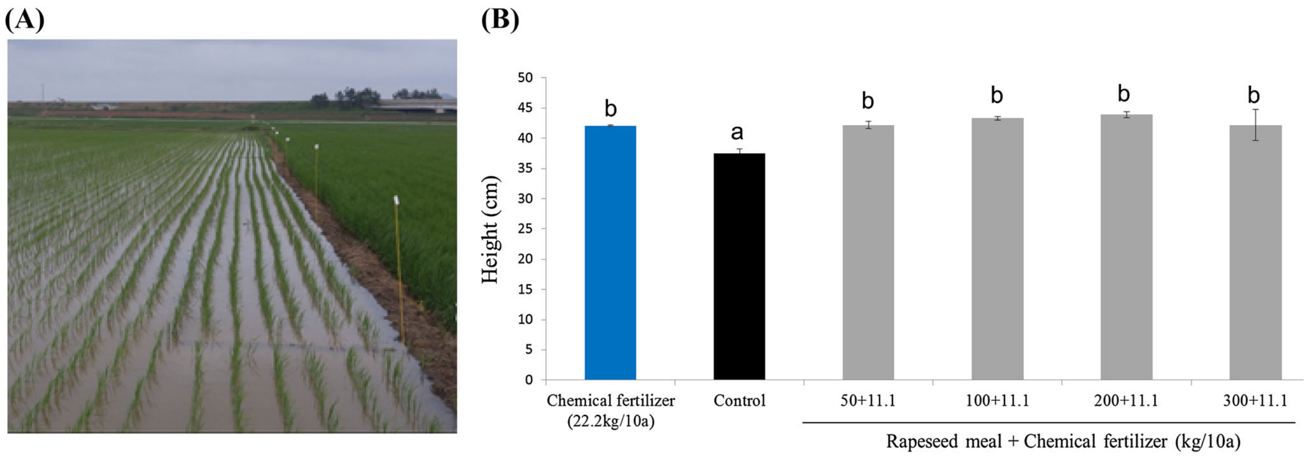


Fig. 2 Rice plants grown on a paddy soil supplemented with a chemical fertilizer (22.2 kg/01. ha) and a mixture of rapeseed meal (0, 50, 100, 200, 300 kg/0.1 ha) and chemical fertilizer (11 kg/0.1 ha) (**A**) and the effect of treatments with the mixture of rapeseed meal and chemical fertilizer on plant height at 30 days after treatments (**B**). Bars are mean ± standard error ($n = 10$). Different lowercase letters in the figure indicate significant difference at $P < 0.05$ by Tukey's test

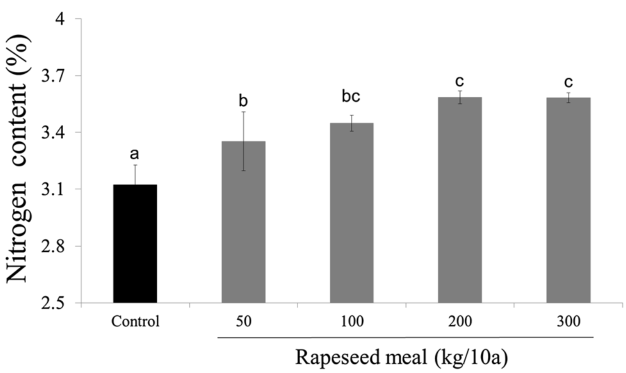
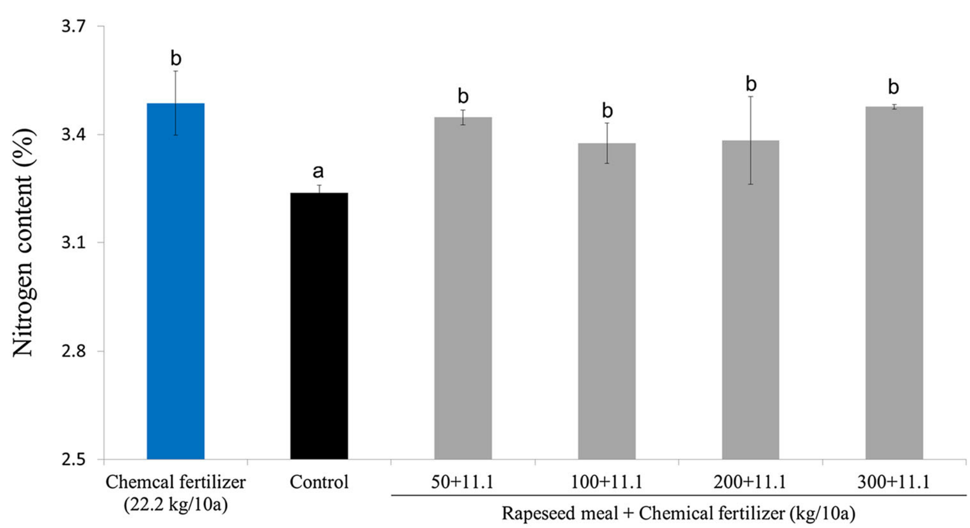


Fig. 3 Total nitrogen contents in leaves of rice plants grown in paddy fields supplemented with rapeseed meals. Measurements were taken in leaves collected 30 days after the treatment. Different lowercase letters in the figure indicate significant difference at $P < 0.05$ by Tukey's test

rate of rapeseed meal or the mixture of rapeseed meal and chemical fertilizer (Table 3). Compared with untreated plants, all the yield components were increased with increasing application rate of rapeseed meal alone to 100 kg/0.1 ha, but it plateaued with further increase in the application rate. In treatments with the mixture of chemical fertilizer and rapeseed meal, the ratio of dry weight per plant, culm length, panicle length, and the yield index was increased at the application rate of 100–200 kg/0.1 ha of rapeseed meal, but plateaued as the level of rapeseed meal in the mixture increased to 300 kg/0.1 ha. There was no difference in the rate of maturity and the thousand grain weight between the samples treated with the mixture of chemical fertilizer and rapeseed meal and samples treated with chemical fertilizer only.

Fig. 4 Total nitrogen contents in leaves of rice plants grown in paddy fields supplemented with a mixture of rapeseed meal and chemical fertilizer. Measurements were taken in leaves collected 30 days after the treatment. Different lowercase letters in the figure indicate significant difference at $P < 0.05$ by Tukey's test



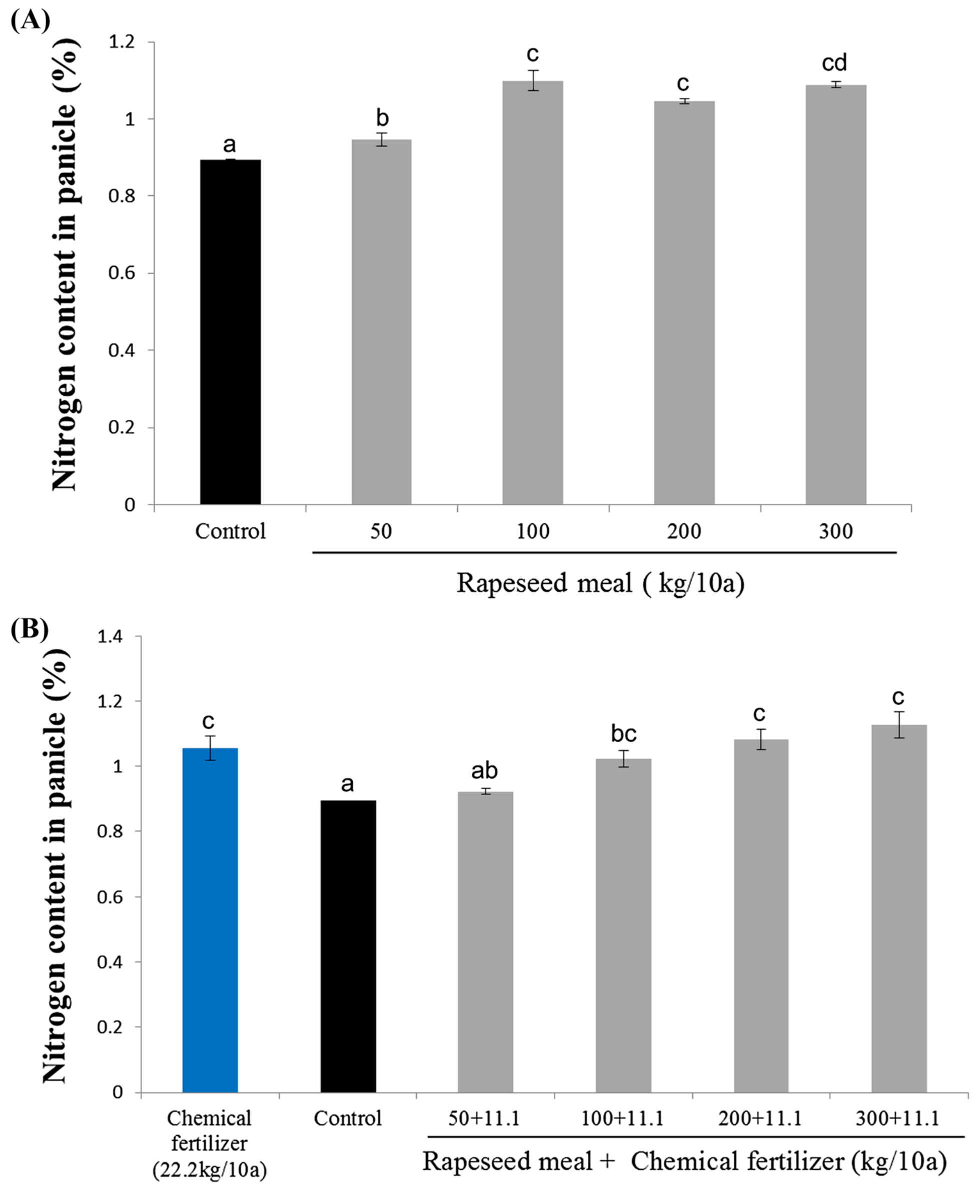


Fig. 5 Total nitrogen contents in the panicle of rice plants grown in paddy fields supplemented with rapeseed meal (**A**) or a mixture of rapeseed meal and chemical fertilizer (**B**). Measurements were taken at the panicle formation stage. Different lowercase letters in the figure indicate significant difference at $P < 0.05$ by Tukey's test

Eco-friendly agricultural products refer to agricultural products produced by preserving and maintaining the agricultural ecosystem and environment through the recycling agricultural, livestock and forestry by-products and by minimizing or limiting the chemical materials such as synthetic pesticides, chemical fertilizers and antibiotics and antibacterial agents. Eco-friendly agricultural products are categorized into 'organic agricultural products' and 'non-pesticide agricultural products' according to production methods and materials used in South Korea. 'Organic agricultural products' are grown without using organic synthetic pesticides and chemical fertilizers, and 'non-pesticide agricultural products' are classified as agricultural products that do not use organic synthetic pesticides and are cultivated using chemical fertilizers less than 1/3 of the recommended amount. Therefore, the present study aimed to determinate the optimal application levels of rapeseed meal for 'organic agricultural cultivation' and 'non-pesticide agricultural cultivation' method by treating rapeseed meal alone or mixed with chemical fertilizer and examining its effects on rice yield. Interestingly, the numbers of spikelet per panicle in treatments with the mixture of chemical fertilizer and rapeseed meal are the higher than those of other treatments. Another notable point is that the treatment of rapeseed meal alone with 50 kg/10a showed the highest value of yield index. These results clearly indicate the positive effect of rapeseed meal on rice yield and yield component in both treatment methods (rapeseed meal alone or mixed with chemical fertilizer).

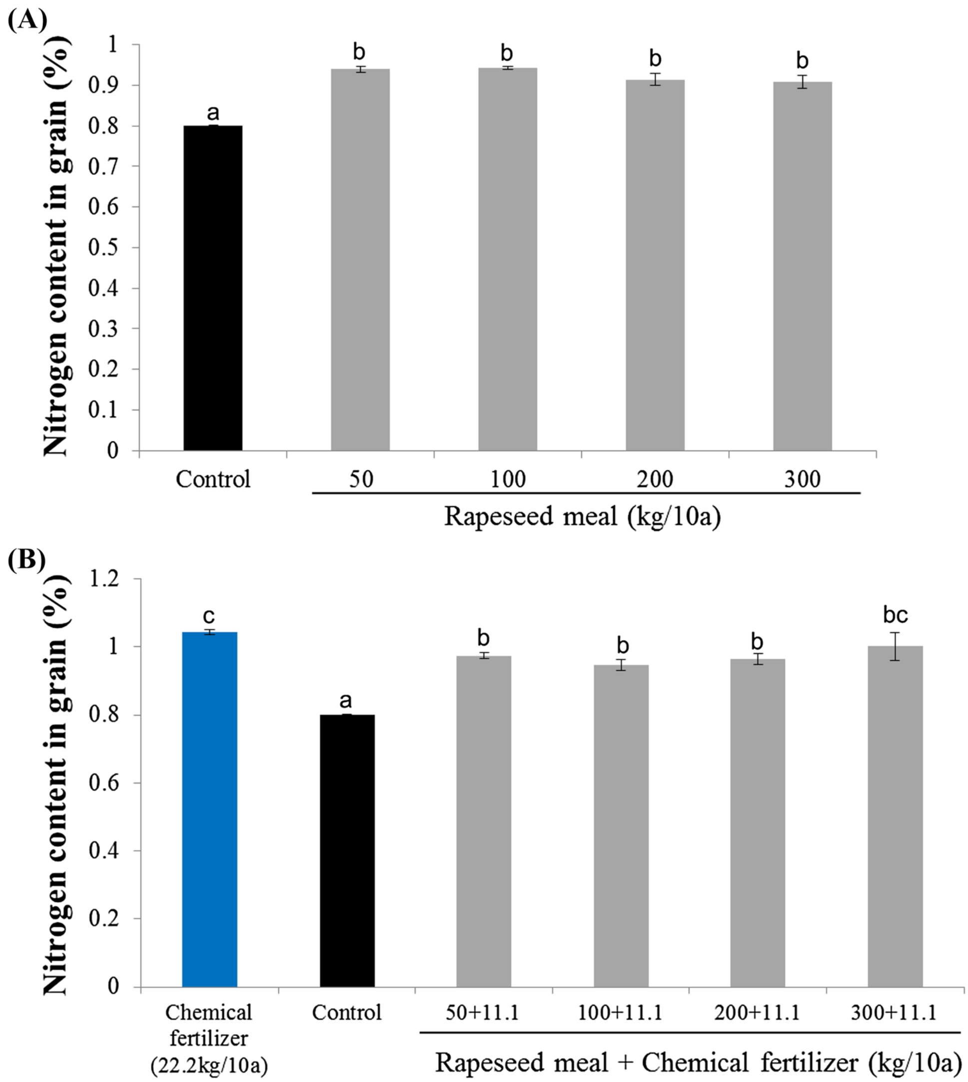


Fig. 6 Total nitrogen contents in grain of rice plants grown in paddy fields supplemented with rapeseed meal (**A**) or a mixture of rapeseed meal and chemical fertilizer (**B**). Measurements were taken at harvest. Different lowercase letters in the figure indicate significant difference at $P < 0.05$ by Tukey's test

Table 2 Chemical properties of paddy soil treated with rapeseed meal for 90 days

		PH (1:5)	EC (dS/m)	OM (g/kg)	Av.P_2O_5 (mg/kg)	Av.Sio_2 (mg/kg)	Ex.cation ($cmol_c$/kg)			T–N (%)	NO_{3^-}–N (mg/kg)	NH_{4^+}–N (mg/kg)	CEC ($cmol_c$/kg)
							Ca	Mg	K				
Control	No treatment	6.0a	0.21a	18.73a	15.9a	193.9b	5.9a	2.4a	0.28a	0.19bc	0.43a	6.91a	23.1a
Rapeseed meal (kg/0.1 ha)	200	6.0a	0.23bc	16.41a	13.83a	169.7a	5.9a	2.6ab	0.31ab	0.18ab	0.58b	7.57b	23.0a
	300	5.9a	0.26c	16.98a	10.85a	172.4a	5.9a	2.5ab	0.32b	0.17a	0.58b	8.11c	23.0a
Rapeseed meal+Chemical fertilizer (kg/0.1 ha)	200 + 11.1	6.1a	0.22bc	22.19b	27.55b	164.8a	6.6b	2.8c	0.31ab	0.20c	0.65c	9.18d	25.0b

Means in each column followed by different letters differed significantly at $p < 0.05$ (Tukey's test), *EC* electrical conductivity, *OM* organic matter, *T–N* total nitrogen, *Ex. cation* exchangeable cation, *CEC* cation exchange capacity

Table 3 Effects of supplementation with rapeseed meal or a mixture of rapeseed meal and chemical fertilizer on yield components

Treatments		Dry weight (g plant^{-1})	Culm length (cm)	Panicle length (cm)	Spikelet number per panicle	Percent ripening (%)	1000 grain weight (g)	Yield index (%)
Control	No treatment	3.03a	59.4cd	17.9a	79.2a	79.0a	20.1a	100a
Rapeseed meal (kg/0.1 ha)	50	4.08b	61.1d	18.8ab	88.5abc	90.5b	23.8b	128d
	100	4.07b	61.9d	18.8ab	88.8abc	89.7b	24.0b	125d
	200	4.02 b	61.0d	18.3ab	86.0abc	89.6b	23.9b	121cd
	300	3.83b	58.2c	18.1ab	88.4abc	86.4ab	21.8ab	111abc
Chemical fertilizer (kg/0.1 ha)	22.2	3.48ab	53.1a	18.6ab	84.0ab	80.7a	20.1a	100a
Rapeseed meal+Chemical fertilizer (kg/0.1 ha)	50 + 11.1	3.76b	55.5b	18.8ab	87.5abc	81.2a	20.1a	104ab
	100 + 11.1	4.09b	57.8bc	19.7ab	94.9bc	80.0a	20.3a	111abc
	200 + 11.1	4.22b	57.6bc	20.0b	95.6bc	81.6a	20.6a	116bcd
	300 + 11.1	3.93b	57.4bc	19.5ab	100.5c	80.5a	20.4a	109abc

Means in each column followed by different letters differed significantly at $p < 0.05$ (Tukey's test)

Based on the results presented herein, the application of rapeseed meal at the rate of 50–100 kg/0.1 ha is the optimal application level that will increase rice yield and in combination with a chemical fertilizer at a rate of 11 kg 0.1 ha improves the nitrogen content.

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