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Effect of Rapeseed Green Manure Amendment on Soil Properties and Rice Productivity

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Green manure crops can be used as alternatives to mineral fertilizers because they improve soil structure and nutrient content of soil. Here, we evaluated the effect of partial replacement of mineral nitrogen (N) fertilizer with rapeseed residue green manure on soil properties and rice productivity in a rice–rapeseed double-cropping system. The treatments were comprised of four levels of mineral N fertilizer and recommended levels of phosphate and potash fertilizers. Rice clum and panicle length did not differ between treatments. However, the proportion of ripened grains and 1,000-grain weight of rice plants were greater under rapeseed residue amendments than those under 100% conventional mineral N fertilizer treatments. Paddy soils treated with rapeseed residues had greater soil organic matter and exchangeable cations than those treated with mineral N fertilizer alone. Thus, rapeseed residues applied as green manure can serve as alternative N sources in sustainable rice–rapeseed double-cropping systems.

Keywords Biodiesel, green manure, nitrogen, rapeseed, rice

Introduction

Rice represents about 90% of total grain produced in Korea (MAF 2007) and constitutes a major source of income for farmers (Ok et al. 2011a). However, recent increases in fertilizer prices, wages, and land value have made rice production expensive. Furthermore, economic growth in Korea has resulted in increased demand for high-quality foods that are safe for individuals and whose production does not affect the environment negatively. To protect the environment, farmers must produce rice using environmentally friendly soil amendments as alternatives to mineral fertilizers. Mineral fertilizers, especially nitrogen (N) fertilizers, are commonly used to increase the quality and productivity of rice crops in Korea. However, the overuse of such fertilizers can lead to contamination of soil and groundwater. The use of organic and green manure can maintain organic matter levels in agricultural soils (Ladd et al. 1994; Awad et al. 2012). Additionally, the decomposition of

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green manure has been shown to increase the soil N available to plants through increased N mineralization in rice paddies (Diekman, De Datta, and Ottow 1993; Wu et al. 2012). Therefore, it is important to identify and evaluate alternative N sources for crop production that do not contribute to environmental pollution (Choi and Daimon 2008).

A few plant species cultivated in Korea are suitable for use as green manure. Additionally, the use of green manure has only been evaluated in a few areas during winter, which is characterized by poor growth when compared with the summer season. Consequently, application of green manure to rice-based cropping systems has been studied in only a few cases. For example, the uses of hairy vetch (Kim et al. 2002; Jeon et al. 2011b) and Chinese milk vetch (Yang et al. 2002; Son et al. 2004) for leguminous and rye plants (Jo et al. 2008) and barley (Son et al. 2004) for nonleguminous plants have been studied. It is also necessary to identify a locally available and novel, green manure crop because the seeds for all currently available green manure crops in Korea are imported.

According to the United States Department of Agriculture (USDA) Foreign Agricultural Service (FAS), Korea is moving to reduce greenhouse gas emissions through increased usage of biodiesel (MIFAFF 2008). To this end, the government has announced plans to gradually increase the biodiesel blend ratio from its current level of 1% to 3% by 2012. The objective is to increase biodiesel usage while minimizing dependence on imported feedstocks for biofuel production (Ahmad et al. 2012). To improve the local supply of feedstocks, the Ministry of Food, Agriculture, Forestry, and Fisheries (MIFAFF) announced a pilot project to produce rapeseed in several provinces on an estimated 1,500 ha in 2007. In 2008, the program was revised to gradually increase the area planted from 1,500 ha to 45,000 ha by 2012. To realize these goals, farmers were required to cultivate fallow paddy fields with rapeseed during winter due to the limited amount of land available for cultivation (Nam et al. 2008).

Many previous studies conducted to evaluate rapeseed plants as green manure have shown that they have great potential for controlling soil-borne diseases, nematodes, and weeds (Muehlchen, Rand, and Parke 1990; Mojrahedi et al. 1993; Boydston and Hang 1995; Al-Khatib, Libbey, and Boydston 1997; Petersen et al. 2001). For example, the growth of numerous crop and weed species was suppressed by adding rapeseed residues to soil (Purvis, Jessop, and Lovett 1985). Additionally, the use of rapeseed residue as a green manure can be a suitable alternative to inorganic N fertilizer during rice cultivation.

However, few studies have been conducted to evaluate the use of rapeseed as an organic fertilizer for succeeding rice crops. Therefore, this study was conducted to evaluate the potential for rapeseed residue green manure as a partial replacement for mineral N fertilizer in a rice–rapeseed double-cropping system. The successful use of rapeseed green manure to support succeeding rice crops will lead to increased land area for the cultivation of rapeseed for biodiesel production in Korea.

Materials and Methods

Rapeseed Cultivation and Harvest

Rapeseed (*Brassica napus* cv. Sunmang) was cultivated from October 2007 to June 2008 in Yeonggwang, Jeollanam-do Province, Korea. This region is located in southwestern Korea and is the primary rice production area in the country. The Yeonggwang region has also been designated for the cultivation of rapeseed for biodiesel production by the Korean government (Nam et al. 2008). After harvesting seedpods on 13 June 2008, vegetative parts of plants including the roots up to a depth of 20 cm were chopped and incorporated into the paddy soil and used as a medium for rice cultivation in a pot experiment.

Soil Analysis, Preparation, and Rapeseed Incorporation

The physicochemical properties of the paddy soil used in this study were determined by the Korean standard methods (NIAST 2000). Soil pH and electrical conductivity (EC) (1:5 soil-to-solution ratio) were measured using a pH meter and EC meter (Orion 3-Star, Thermo-Scientific, USA), respectively. Cation exchange capacity (CEC) was analyzed by the 1.0 N ammonium acetate method (NIAST 2000), and organic-matter content was measured using the Walkley–Black method (Nelson and Sommers 1996). Available phosphorus (P) was analyzed by the Lancaster method (NIAST 2000) using an UV spectrophotometer (UV-1800, Shimadzu, Japan), while available silicon dioxide (SiO_2) was analyzed by the 1.0 N sodium acetate method (NIAST 2000) using an UV spectrophotometer (U-3010, Hitachi, Japan). Exchangeable forms of calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^+) were analyzed using an inductively coupled plasma (ICP) spectrometer (GBC Integra XL, GBS, Australia).

Based on the soil analysis, mineral fertilizer was applied at rates of 110, 30, and 30 kg ha^{-1} for N, P, and K, respectively, according to the recommendations of the Rural Development Administration (RDA).

Pots (75 × 45 × 20 cm) were filled with paddy soil and the rapeseed residues were applied at the same level harvested in the cultivation field. The treatments consisted of four levels (0, 30, 70, and 100%) of mineral N fertilizer, while phosphate (P) and potash (K) fertilizers were applied at the recommended levels across the four treatments. Nitrogen, P, and K were applied as urea, fused superphosphate, and potassium chloride, respectively. The treatments were as follows: (1) 100% of recommended amount of N applied as mineral N fertilizer + recommended P and K levels (conventional 100%), (2) 70% of recommended amount of N applied as mineral N fertilizer + rapeseed residues + recommended P and K levels (conv. 70% + rapeseed), (3) 30% of recommended amount of N applied as mineral N fertilizer + rapeseed residues + recommended P and K levels (conv. 30% + rapeseed), and (4) rapeseed residues alone + recommended P and K levels (rapeseed alone). Fifty percent of the mineral N was used as basal fertilizer, and the other 50% was applied during the panicle-formation stage.

Rice Growth and Yield as a Succeeding Crop

Seedlings of rice plants (*Oryza sativa* L. cv. Ilmibyeo) (16 cm, 40 days after sowing) were transplanted to pots containing the amended paddy soil. Rice plants were then transplanted in 10 hills (8 rice plants $hill^{-1}$) in each pot at a spacing of 25 × 15 cm. The plants were then grown under natural conditions in a plastic greenhouse. Plant length and chlorophyll content (SPAD-502, Minolta Co. Ltd., Japan) of rice plants were measured during the vegetative stage, 20 days after transplanting (DAT), and repeated every 10 days. The SPAD values were taken at the center of the leaf blade next to the primary vein to estimate N status of the plant.

Samples of rice plants were taken during maximum tillering and at harvesting. All plant samples were separated into green leaf blades (leaf), clum plus sheaths (stem), and panicles, when present. Panicles were hand threshed and filled spikelets were then separated from empty spikelets by submerging the spikelets in tap water. The filled spikelets were then oven dried at 50 °C to a constant weight to determine individual grain weight. Rice yield components such as the panicle number, spikelets per panicle, proportion of ripened grain, and 1,000-grain weight were calculated (Yoon et al. 2004).

Analyses of Plant Samples

Nitrogen content of rapeseed green manure crop (at harvest) and rice plants as a succeeding crop (at maximum tillering and harvesting stage) were determined to calculate N supply from the green manure and uptake by the rice plants. Prior to N and C analyses, the plant samples were oven dried for 48 h at 70 °C, weighed, and then ground. Nitrogen and C content of the plant samples were determined by the dry-combustion method using an Elemental Analyzer (Flash EA 1112, Thermo-Scientific, USA).

Statistical Analyses

Differences between treatment groups were evaluated by one-way analysis of variance (ANOVA) using the SAS program version 9.1 (SAS Institute 2003). Treatment means were separated using the Tukey's least significant difference (LSD). A $P < 0.05$ was considered to indicate statistical significance.

Results

Soil Physicochemical Properties

The physicochemical properties of the paddy soil used in this study are shown in Table 1. The pH and EC of the paddy soil were 6.3 and 0.21 dS m^{-1}, respectively. Organic matter and available P were 28 g kg^{-1} and 85 mg kg^{-1}, respectively. The concentrations of the exchangeable forms of Ca^{2+}, Mg^{2+}, and K^+ were 6.1, 0.8, and 0.55 $cmol_{(+)}$ kg^{-1}, respectively. With the exception of K and SiO_2, these values were within the optimum range for paddy fields in Korea.

Incorporation of Rapeseed Green Manure

Table 2 summarizes the N content, fresh weight, and dry weight of harvested green manure. The plant density and aboveground biomass yields of rapeseed were 153,000 plants ha^{-1} and 100.5 kg Mg ha^{-1}, respectively. Nitrogen accumulation in all parts of plants, excluding

Table 1
Chemical properties of paddy soil before incorporation of green manure

	pH (1:5)	EC (1:5)	OM (g kg^{-1})	Av. P_2O_5 (mg kg^{-1})	K ($cmol_{(+)}$ kg^{-1})	Ca ($cmol_{(+)}$ kg^{-1})	Mg ($cmol_{(+)}$ kg^{-1})	Av. SiO_2 (mg kg^{-1})
Soil	6.3	0.21	28	85	0.55	6.1	0.8	251
Optimum range[a]	6.0–6.5		25–30	80–120	0.25–0.30	5.0–6.0	1.5–2.0	130–180

[a]Korean Soil Information System (2010).

Table 2
Fresh weight, dry weight, and N content of rapeseed sampled during the harvesting stage

Plant parts	No. of plants (1000 plants ha^{-1})	Fresh weight (Mg ha^{-1})	Dry weight (Mg ha^{-1})	T – N (%)	N content (kg ha^{-1})	C/N[a] ratio
Shoot	153 ± 19	98.61 ± 10.09	26.26 ± 3.73	0.54 ± 0.02	141 ± 20	61
Root	153 ± 19	1.90 ± 0.47	0.45 ± 0.10	0.47 ± 0.01	2 ± 0	85
Total	153	100.5	26.72	0.54	143	63

the seeds, was 143 kg N ha^{-1} by the harvesting stage. The shoot dry weight was approximately 60 times greater than the root dry weight at a depth of 20 cm, while the C/N ratio was 63.

Rice Growth and Yield

The growth of rice plants was inhibited for 10 DAT. During the vegetative stage (from 20 to 80 DAT), the length of rice plants cultivated using 100% mineral fertilizer was greater than that of all other treatments (Figure 1). However, at 80 DAT, there were no significant differences in the length of rice plants that received the conventional 100% mineral fertilizer treatment and those that received the conv. 70% + rapeseed treatment.

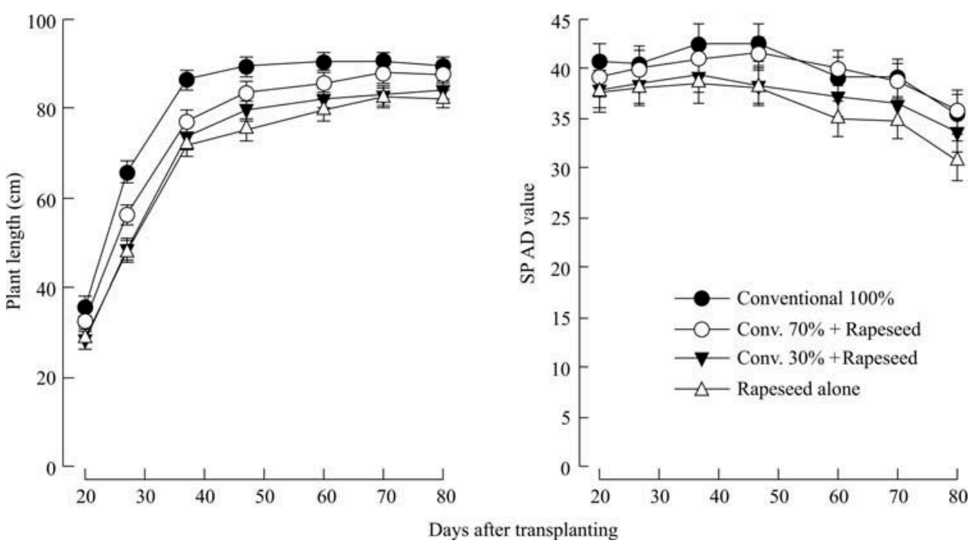

Figure 1. Changes in plant length and SPAD value of rice grown in rapeseed-amended paddy soil. Vertical bars indicate the standard error. Conventional 100% consisted of 100% of the recommended amount of N as a mineral fertilizer. Conv. 70% + rapeseed and conv. 30% + rapeseed contained 70% and 30% of the recommended levels of N fertilizer and rapeseed residues as green manure. Rapeseed alone consisted of rapeseed residues without mineral N fertilizer.

There were no significant differences in the SPAD value of rice plants between treatments. However, SPAD value of the conv. 70% + rapeseed group was slightly less than that of plants that received the conventional 100% treatment for up to 50 DAT. Thereafter, the SPAD value of the rice plants that received the conv. 70% + rapeseed treatment was similar to or greater than that of plants under the conventional 100% treatment. Conversely, plants treated with rapeseed alone and with conv. 30% + rapeseed had lower SPAD values, which affected the uptake of N by the plants.

At the maximum tillering stage, the dry weight of the rice plants that received the conventional 100% treatment and those that received the conv. 70% + rapeseed treatment were 7.0 and 6.3 g plant^{-1}, respectively (Table 3). Both the dry weights of plants treated with rapeseed alone and conv. 30% + rapeseed were 37% less than those of the plants that received the conventional 100% treatment. Rice plants that received the conv. 70% + rapeseed treatment had greater N content [4% dry matter (DM)] than the plants that received the conventional 100% treatment, conv. 30% + rapeseed, and rapeseed alone treatments (Table 3).

There were no differences ($P > 0.05$) in lengths of clums and panicles of plants among treatments (Table 4). The mean lengths of clums and panicles of rice plants were 55.8 cm and 14.7 cm, respectively.

The effect of incorporating rapeseed residues on N uptake by rice plants, dry weight, and N content varied with mineral N fertilizer levels (Figure 2). Dry weight and N content of rice leaves and stems declined as the mineral N fertilizer levels decreased. The N content of the spikelets of rice plants treated with conv. 70% + rapeseed was greater than in plants that received the conventional 100% treatment, but was similar in plants that received the conv. 30% + rapeseed treatment.

The number of panicles in harvested rice plants decreased with decreasing mineral N fertilizer level (Table 5). However, there were no significant differences in the number of spikelets per panicle between treatments. Conversely, the proportion of ripened grain (81.8%) and 1,000-grain weight (15.8 g plant^{-1}) were greatest in rice plants that received the rapeseed residue only, and these values decreased as the mineral fertilizer level increased. However, the proportion of ripe grain did not differ ($P > 0.05$) between plants that received the 100% mineral N fertilizer and those that received the conv. 70% + rapeseed treatment. The yield of rice from plants that received the conventional 100%

Table 3
Biomass yield and N content of rice (at the maximum tillering stage) grown after incorporation of rapeseed

	Fresh weight (g plant^{-1})			Dry weight (g plant^{-1})			N content (mg plant^{-1})		
Treatment	Leaf	Stem	Total	Leaf	Stem	Total	Leaf	Stem	Total
Conventional (100%)	19.7 a[a]	30.3 a	50.0 a	4.0 a	3.0 a	7.0 a	145 a	64 ab	209 a
Conv. 70% + rapeseed	18.5 a	26.1 b	44.5 b	3.6 a	2.7 a	6.3 a	153 a	70 a	223 a
Conv. 30% + rapeseed	13.1 b	17.1 c	30.2 c	2.5 b	2.0 b	4.4 b	104 b	53 b	157 b
Rapeseed alone	12.6 b	16.9 c	29.5 c	2.6 b	1.9 b	4.4 b	87 c	36 c	123 b

Note. Rapeseed (143 kg N ha^{-1}) was applied as green manure.
[a]Values in a column followed by the same letter are not significantly different at the 0.05 probability level.

Table 4
Effect of rapeseed residues and fertilizer treatments on clum and panicle lengths of rice plants at the harvesting stage

Treatment	Clum length (cm)	Panicle length (cm)	Total (cm)
Conventional 100%	55.9	14.3.	70.2
Conv. 70% + rapeseed	56.1	15.0	71.2
Conv. 30% + rapeseed	55.7	14.7	70.3
Rapeseed alone	55.4	14.6	70.1
	NS	NS	NS
Mean	55.8	14.7	70.5

Note. NS, not significant.

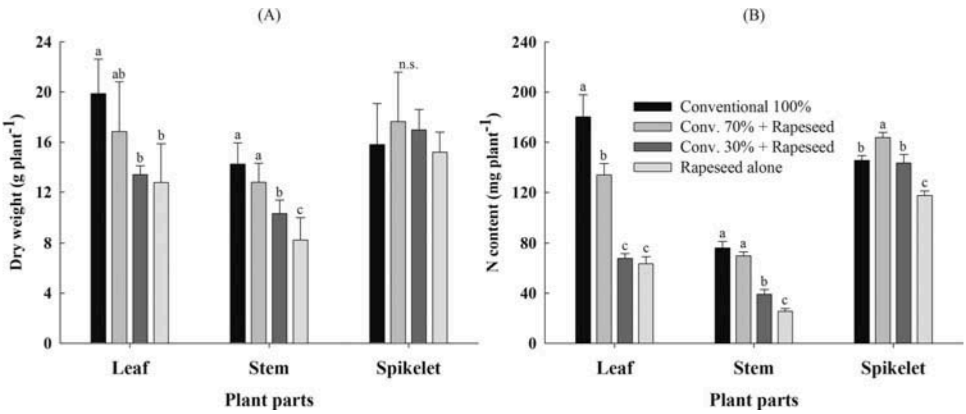

Figure 2. Changes in dry weight (A) and N content (B) of rice plants at the harvesting stage in response to incorporation of rapeseed residues and mineral fertilizer. Significant at the 0.05 probability level.

treatment was significantly greater than that of plants that received the conv. 30% + rapeseed and the rapeseed alone treatments but did not differ ($P > 0.05$) from the yields of plants that received the conv. 70% + rapeseed treatment. The yield indexes were 98.9%, 91.7%, and 82.3% for plants that received the conv. 70% + rapeseed, conv. 30% + rapeseed, and rapeseed alone treatments, respectively.

Soil Properties after Incorporation of Rapeseed Residue

The pH of amended paddy soil did not differ between treatments. Application of the rapeseed residues led to an increase in the organic material of paddy soil when compared with soil that received the conventional 100% treatment. When compared with the conventional 100% mineral N treatment, the level of exchangeable cations such as K^{+}, Ca^{2+}, and Mg^{2+} was greater in rapeseed residue–amended soil. Conversely, the content of available P was greatest in paddy soil that received conventional 100% mineral N treatment but declined with the reduction in mineral N fertilizer levels and inclusion of rapeseed residues (Table 6).

Table 5

Effects of rapeseed residues and fertilizer treatments on yield components and yield index of rice plants at the harvesting stage

Treatment	Panicle number	Spikelet number per panicle	Percent ripened (%)	1000-grain weight (g plant^{-1})	Yield (g plant^{-1})	Yield index
Conventional 100%	20.3 a[a]	69.0 n.s	69.8 b	14.6 c	14.25 a	100
Conv. 70% + Rapeseed	19.2 a	68.6 n.s	71.4 b	15.0 ab	14.10 a	98.9
Conv. 30% + Rapeseed	16.2 b	71.9 n.s	72.9 b	15.4 ab	13.07 b	1.7
Rapeseed alone	13.2 c	68.9 n.s	81.8 a	15.8 a	11.73 c	82.3

[a]Values in a column followed by the same letter are not significantly different at the 0.05 probability level.

Table 6

Effects of rapeseed residues and fertilizer treatments on the physicochemical properties of rice paddy soil at the harvesting stage

Treatment	pH (1:5)	OM[a] (g kg^{-1})	Av. P_2O_5 (mg kg^{-1})	K^+ (cmol$_{(+)}$ kg^{-1})	Ca^{2+} (cmol$_{(+)}$ kg^{-1})	Mg^{2+} (cmol$_{(+)}$ kg^{-1})	SiO_2 (mg kg^{-1})
Conventional 100%	6.88	22.3 b[b]	54.0 a	0.10 d	4.5 b	1.8 b	96.6 ab
Conv. 70% + Rapeseed	6.89	27.0 a	48.8 ab	0.36 c	4.9 a	2.0 a	93.0 b
Conv. 30% + Rapeseed	6.90	29.0 a	45.8 b	0.46 b	4.9 a	2.1 a	91.3 b
Rapeseed alone	6.92	27.6 a	44.7 b	0.52 a	4.8 a	2.1 a	107.2 a
	NS	*	*	*	*	*	*

Note. NS, not significant ($P > 0.05$).
$^*P < 0.05$.
[a]OM, organic matter.
[b]Values in a column followed by the same letter are not significantly different at the 0.05 probability level.

Organic matter, P, K^+, Ca^{2+}, and SiO_2 content of the soil were lower during rice cultivation than prior to cultivation, whereas the opposite was true for soil pH and Mg content. The difference in soil exchangeable cations before and after rice cultivation was greater under conventional treatment than in rapeseed residue–treated soils. The level of organic matter was similar before and after rice cultivation in rapeseed residue–treated soils. Conversely, the available P and SiO_2 contents of soils that received the rapeseed residues were less than those that received the conventional treatment.

Discussion

Cultivation of Rapeseed Plants

The present study results suggest that there is a potential for using rapeseed residues as green manure to partially replace mineral N fertilization in rice production. The use of rapeseed residues as green manure also provides a means of disposal for residues remaining after harvesting seed for biodiesel production (Ok et al. 2011b). Green manure provides benefits to the soil that extend beyond those of mineral fertilizers and agrochemicals. For example, when plants are incorporated into the soil as green manure, they build up the organic-matter content, which improves water retention, reduces compaction, and makes the soil habitat healthy for beneficial organisms (Kuzyakov and Domanski 2000).

Rice is the most important crop in Korea and other countries in East Asia. It is important that farmers employ rice cultivation practices that promote good yields while ensuring the safety of both consumers and the environment, such as organic farming or low-input sustainable agriculture practices (Yoon et al. 2004; Jeon et al. 2011a). In the present study, the effect of partial replacement of mineral N fertilizer with rapeseed residue green manure in a rice–rapeseed double-cropping system on soil properties, rice growth, and yield was evaluated.

Many studies have reported that rapeseed plants are a useful green manure crop that contributes to weed management (Al-Khatib, Libbey, and Boydston 1997; Petersen et al. 2001; Choi et al. 2010) and the suppression of soil-borne diseases (Muehlchen, Rand, and Parke 1990), insects, and nematodes (Mojrahedi et al. 1993) via the production of allelochemicals, especially glucosinolates. However, in Korea, few studies have been conducted to evaluate the relationship between the promoting and inhibitory effects of the incorporation of rapeseed plants on the growth of succeeding rice plants. In the present study, the cultivation of rapeseed plants with a biomass of 100,510 kg ha^{-1} resulted in the accumulation of 143 kg N ha^{-1}, which when incorporated into the soil contributed to the growth and yield of the succeeding rice plants (Tables 2 and 6). In the Honam Region, Son et al. (2004) reported N accumulation values of 39 kg ha^{-1} and 178 kg ha^{-1} in cultivated crops in response to soil amendment with barley and Chinese milk vetch green manures, respectively. The rice yields were 95% and 101% in response to barley and Chinese vetch green manure treatments, respectively.

Nitrogen Contribution of Rapeseed Residues for Rice Cultivation

Generally, green manure crops should be harvested and applied to the soil during vegetative growth stages such as the flowering stage to maximize N uptake and growth of succeeding plants. However, in the present study, rapeseed residues were applied as a green manure after harvesting the seeds for biodiesel production. At this stage of growth, the plants were highly lignified and had a high C/N ratio, leading to the reduction in growth of the succeeding rice crop. Some chemical constituents of green manure such as the lignin-to-N ratio and the tannin-to-N ratio control the release of N and slow nutrient mineralization and decomposition rates (Becker et al. 1994; Tejada and Gonzalez 2006; Tejada et al. 2008). Additionally, the release of N is affected by the C/N ratio of the manure, timing, and depth of incorporation; type of tillage management; water content; and texture of the soil (Sarrantonio and Scott 1988; Francis, Haynes, and Williams 1995).

Incorporation of rapeseed residues inhibited early growth in rice seedlings due to a delay in the decomposition of organic materials (Figure 1) and possibly the release of inhibitors during decomposition. These results indicate that the growth of the succeeding rice plants could have been inhibited by growth inhibitors from the decomposition of rapeseed residues that accumulate in the soil. However, the growth rate of plants that received the conv. 70% + rapeseed treatment recovered from the maximum tillering stage and had growth values similar to plants under the conventional 100% treatment (Tables 3 and 4). The release of N from crop residues can be slow or rapid depending on the quality of the residues (Cherr, Scholberg, and McSorley 2006). The rate of release of nutrients from organic fertilizers can have positive effects on N management in the soil. Rapid release enhances early N uptake by the succeeding crop but may lead to N loss through leaching if crop demand is lower than the amount of N being released. Slow release would guarantee a continuous supply of N to the crop throughout most of the growing season; however, if the amount of N released is too small, its contribution to crop growth may not significantly boost crop performance (Sakala, Kumwenda, and Saka 2003).

Seeds of the succeeding crop should be planted several weeks after incorporation of the green manure to avoid phytotoxicity, which can be caused by rapeseed green manure (Scott and Knudsen 1999; Choi et al. 2008). Under greenhouse conditions, Papavizas (1966) found that a 3-week decomposition period was necessary prior to planting a succeeding pea crop when rapeseed plants were used as green manure. These results are in agreement with those of the present study, in which the growth of rice plants increased with time following the incorporation of rapeseed residues. Indeed, the difference in the growth of rice plants between the conv. 70% + rapeseed treatment and conventional 100% treatment decreased with time. Conversely, we previously demonstrated that amending soil with conv. 70% + rapeseed inhibited weed density and dry weight of rice by 63% and 64%, respectively, when compared with the conventional 100% mineral N fertilizer treatment. In the same study, soil amendment with rapeseed alone inhibited weed density and dry weight by 85% and 88%, respectively (Choi et al. 2009). These results suggest that rapeseed plants contribute to weed management by inhibiting the growth of weeds.

Incorporation of rapeseed residues with 70% mineral fertilizer resulted in similar tiller numbers, panicle numbers, and percentage of ripened grains as the conventional 100% treatment (Table 5). In contrast, the number of filled spikelets and 1000-grain weight of rice increased significantly in response to treatment with green manure. Tiller numbers are the most important determinant of rice yield. Indeed, although the lengths of culms and spikelets of the rice plants were similar among treatment groups, rice yield differed significantly (Tables 4 and 5). During the early growing season, it is important to promote seedling root growth in soil using incorporated residues. In addition, increasing the number of tillers is important to ensure a good harvest. Yang et al. (2002) and Son et al. (2004) reported that incorporation of green manure promoted plant growth and increased the number of tillers. Additionally, Prasad et al. (2002) reported that application of green manure increased the number of filled spikelets and straw yields.

Rice yield did not differ ($P > 0.05$) between the conv. 70% + rapeseed treatment and the conventional 100% treatment (Table 5). Results indicate that N uptake by the succeeding rice plants was approximately 3.3 kg $10a^{-1}$ from the input N content (14.3 kg $10a^{-1}$) of the incorporated rapeseed residues due to delayed N mineralization. Delayed mineralization can reduce plant-available N during peak crop demand (Vyn et al. 1999), but this may become available to succeeding crops (Garwood, Davies, and Hartley 1999) or promote postharvest leaching losses (Karen and Doran 1991).

Soil Quality from Incorporated Rapeseed Residues

Incorporation of rapeseed residue green manure increased levels of organic matter and cations and decreased levels of available P. Furthermore, the pH values increased slightly as the amount of rapeseed residues increased, although this change was not statistically significant. Yang et al. (2002) reported that the physicochemical properties of paddy soil were improved in response to the incorporation of Chinese milk vetch green manure. They also reported that soil amendment with Chinese milk vetch increased total N, organic matter, and porosity ratio but decreased phosphorus pentoxide (P_2O_5,), bulk density, and solid phase ratio. The use of green manure can reduce the need for basal dressing or topdressing with mineral fertilizer because the added organic material may help maintain soil fertility by acting as a source of soil humus and improving the soil physical and chemical properties (Yasue 1991). Our results do not support the findings of Liu and Hue (2001) and Ortiz and Hue (2008), who reported that soil pH increased after the incorporation of organic material due to the production of ammonium (NH_4^+) and its subsequent oxidation to nitrate.

Soil properties were greater before rice cultivation but declined thereafter. The decomposition of rapeseed residue green manure released nutrients such as N and organic matter into the soil. The uptake of nutrients by plants during rice growth decreased the organic matter and nutrient levels in the soil. The reduction in soil exchangeable cations and organic matter was greater in soil under the conventional 100% mineral N treatment than under rapeseed treatments.

In this study, soil chemical properties such as organic matter and exchangeable Mg^{2+} increased in response to the application of green manure. The practice of inorganic fertilization alone cannot maintain the soil quality required to sustain crop productivity. The incorporation of green manure is recommended because it increases soil quality as measured by organic matter, K^+, Ca^{2+}, Mg^{2+}, and cation exchange capacity (Porter et al. 1999; Tirol-Padre et al. 2007).

Rapeseed residue green manure efficiently improved soil fertility more than the conventional mineral fertilizer treatments in this study. In addition, rapeseed green manure effectively maintained crop yield and enhanced soil properties more than mineral fertilizer application. Increased rapeseed cultivation for biodiesel production will provide sufficient organic materials that can be used as an alternative source of mineral fertilizer (Cherr, Scholberg, and McSorley 2006). It is therefore possible to increase rice grain yields by using rapeseed green manure in conjunction with reduced levels of mineral fertilizers in Korea. Reduced use of mineral fertilizers will contribute to sustainable agriculture by increasing the soil quality and protecting the environment, due to reduction in greenhouse gas emissions.

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