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Full Length Research Paper

Effect of different Seed planting methods on green manure biomass, soil properties and rice yield in rice-based cropping systems

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The cultivation of green manure crops plays an important role in soil quality and the sustainability of agricultural systems. Field experiments were conducted during one season (2007/2008) to evaluate the effects of different seeding methods on the biomass and N production of hairy vetch (*Vicia villosa*) and barley (*Hordeum vuglare*). The effects of treatments on rice yield and its components were also investigated. Specifically, the following four treatments were evaluated: broadcasting before rice harvesting (BBRH), partial tillage seeding (PTS), group seeding (GS) and drill seeding (DS). The overall results showed the following ranking of biomass and nitrogen production of hairy vetch by different seeding methods: BBRH > PTS > DS > GS. Additionally, biomass and nitrogen production of barley was lower than those of hairy vetch at all tested seeding treatments. BBRH and PTS treatments led to an increase in soil bulk density, porosity and soil organic content. The application of green manure with BBRH and PTS treatments led to a significant increase in rice yield (5,330 and 5,320 kg ha^{-1}) when compared to conventional fertilization. Based on the results, BBRH and PTS are good practices for production of green manure in paddy soil. Chemical fertilizers can be replaced with hairy vetch as green manure in rice-based cropping systems.

Key words: Green manure, rice, biomass, soil property, seeding method.

INTRODUCTION

The use of herbicides and nitrogen fertilization in agriculture is becoming limited in Korea due to their expense and environmental impact, which has recently caused great concern. Therefore, environmentally-friendly approaches to the cultivation of rice are necessary to ensure adequate crop yield while protecting the environment (Park et al., 2008; Oenema et al., 2009). Cultivation of green manure crops plays an important role in soil quality and sustainability of agricultural systems. Specifically, legume crops may supply nitrogen through the nitrogen fixation process, thereby supplying N for the crop when used as green manure due to its rapid subsequent N mineralization (Brandsaeter et al., 2008). Moreover, it is well known that leguminous crops in rice-based cropping systems improve soil bulk density, soil porosity, soil structure, water holding capacity and soil organic matter (Schulz et al., 1999).

Rice is the most important principal food crop in Korea, with cultivation occurring on a land area of 955,000 ha and a gross grain production of 4.7 million tons in 2006 (MAF, 2007). The Korean government changed the policy of rice production from a high production to a high quality approach in 2002 (Jang, 2010). Green manure has received renewed attention with the emphasis on long-term sustainability of agricultural systems because it can be used as a source of soil nutrients and an alternative to maintenance of soil fertility (Ali, 1999). In addition, Ali (1993) reported that green manure in rice double cropping systems increased rice yield by up to 3.3 ton ha^{-1}.

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Abbreviations: BBRH, Broadcasting before rice harvesting; **PTS,** partial tillage seeding; **BBRH,** broadcasting before rice harvesting; **GS,** group seeding; **DS,** drill seeding.

Moreover, green manure or cover crops have been shown to improve soil chemical and physical properties (Sarrantonio and Gallandt, 2003; Jeon et al., 2008) and weed management (Hatcher and Melander, 2003). In Korea, green manure technology using Chinese milk vetch (*Astrogulus sinicus*) and hairy vetch (*Vicia villosa*) has primarily been studied in rice paddies (Jeon et al., 2010; Kim et al., 2002; Lee, 2010). However, problems with the stability of green manure crop production in paddies after rice harvesting have been observed. Specifically, anoxic conditions are predominant in soil during the growth of rice, which results in fluctuations in redox potential. The changes in redox potential that occur after draining the soil led to changes in the availability of nutrients. For example, redox potential was found to increase after draining the rice field one or two weeks before harvest, which resulted in Fe^{2+} being oxidized to Fe^{3+} (Ratering and Conrad, 1998; Ratering and Schnell, 2000).

Conversely, cultivation of upland crops (hairy vetch and barley) as green manure in oxic fields has been well documented. However, management of these fields is very difficult due to poor drainage and the ability of green manure to survive during winter (Lee et al., 2010). Accordingly, many seeding methods have been developed in Korea. For example, broadcasting before rice harvesting (BBRH) is generally used in rice paddies. Specifically, broadcast sowing culture is relatively less labor intensive than other cultures. However, BBRH is not suitable when using rice straw as mulch for livestock feed after rice harvesting.

These methods require soil plowing after rice harvesting and influence the seeding process by increasing the soil moisture content, thereby delaying the seeding date. Therefore, new technology for seeding of green manure is needed to save labor and fuel after rice harvesting such as partial tillage seeding (PTS). Accordingly, this field experiment study was conducted to evaluate the effects of different seeding methods on the biomass and N production of hairy vetch and barley green manure under rice-based cropping systems. The effects of various treatments on rice yield and its components were also investigated.

MATERIALS AND METHODS

Site description and soil characterization

A field experiment was conducted in paddy soil (fine loamy, mixed, nonacid, mesic, family of Aeric Fluventic Haplaquepts) at the National Institute of Crop Science (NICS), Korea, from October 2007 to October 2008. A green manure-rice rotation system was employed from October 2006 to May 2007 in previously cropped rice mono rice cultures, except for hairy vetch cultures, which was from 2005/2006. The soil used in this experiment was a silt loam (14.8% clay, 52.1% silt and 33.1% sand) with a bulk density of 1.43 g cm^{-3}. The top soil (0 to 15 cm) prior to sowing the green manure crop had an organic matter of 31.1 g kg^{-1} and a pH of 5.5 (soil : water, 1:5).

Experimental layout and treatments

A field experiment was conducted in a paddy soil to evaluate the effects of seeding methods on the biomass production of hairy vetch (*V. villosa*) and barley (*Hordeum vuglare*). Additionally, the effects of green manure on rice yield were investigated. The field experiment was conducted in a randomized complete block with four treatments and three replicates. Specifically, the treatments consisted of broadcasting before rice harvesting (BBRH), partial tillage seeding (PTS), group seeding (GS) and drill seeding (DS). BBRH was conducted by hand on September 26. Rice straw was mulched after rice harvesting on October 8. PTS, GS and DS were conducted on October 9 after rice harvesting. Additionally, PTS and GS treatments were conducted under no tillage conditions. Seeding was conducted using a PTS seeder developed by the Department of Agricultural Engineering, Rural Development Administration, and by Jang Automation Co. (Korea) that was attached to a tractor. Moreover, the partial tillage seeder consisted of eight horizontal rows in a rotary system with a drainage channel in the center of the seeder (Park et al., 1999; Jeon et al., 2008). The experimental design and seeding methods used in this study are shown in Figure 1. The GS seeder (HG10A, Korea) was developed by Hwang Geum Seeder. The GS seeder was designed for hill seeding at a density of 30 by 10 cm. DS was conducted in a 25 cm space after rotary tillage with a tractor (L65, LG, Korea). The seeding rates were 90 and 140 kg ha^{-1} for hairy vetch and barley, respectively. All green manure treatments were conducted without application of chemical fertilizer.

Green manure preparation and incorporation

Prior to incorporation of green manure into the soil, the green manure and canopy height were estimated. Additionally, the aboveground portion and fresh weight were measured before incorporation of green manure and then dried in an oven at 70°C until a constant weight was obtained to determine the dry weight. Moreover, the total carbon (C) and total nitrogen (N) were measured using a CNS analyzer (Leco, USA). The incorporation of green manure into the soil was conducted on May 16, 2007 using a tractor (L65, LG, Korea).

Rice cultivation and measurements

Seedlings of rice (*Oryza sative* L. cv. Pungmibyeo, Japonica type) were transplanted as a succeeding crop (25 days old) using a transplanter machine at a spacing of 30 x 14 cm on June 2. Based on the soil analysis, the chemical fertilizer treatment group consisted of conventional fertilization treatment only and the other treatments did not receive any chemical fertilizer. Additionally, chemical fertilizers were applied as N-P_2O_5-K_2O at rates of 90-45-57 kg ha^{-1} to meet the required contents in soil and the recommended dose for rice cultivation in Korea according to the Rural Development Administration (RDA, 1999). Chemical fertilizers were broadcast and incorporated into the top soil (15 cm) using a plough prior to transplantation of rice in a conventional practice plot. In addition, herbicide (pyrazosulfuron-ethyl; Sungbo Chemical Co. LTD., Korea) was applied at a rate of 30 kg ha^{-1} at seven days after transplanting of rice. To evaluate the effects of different seeding methods on rice yield and production, the rice yield and yield components were estimated. Specifically, the panicle number $hill^{-1}$, number of grains $panicle^{-1}$, ripened grains and 1,000 grains weight were determined during the physiological maturity stage of rice. Rice samples were collected from random areas (4.0 m^2) within each plot (RDA, 1995).

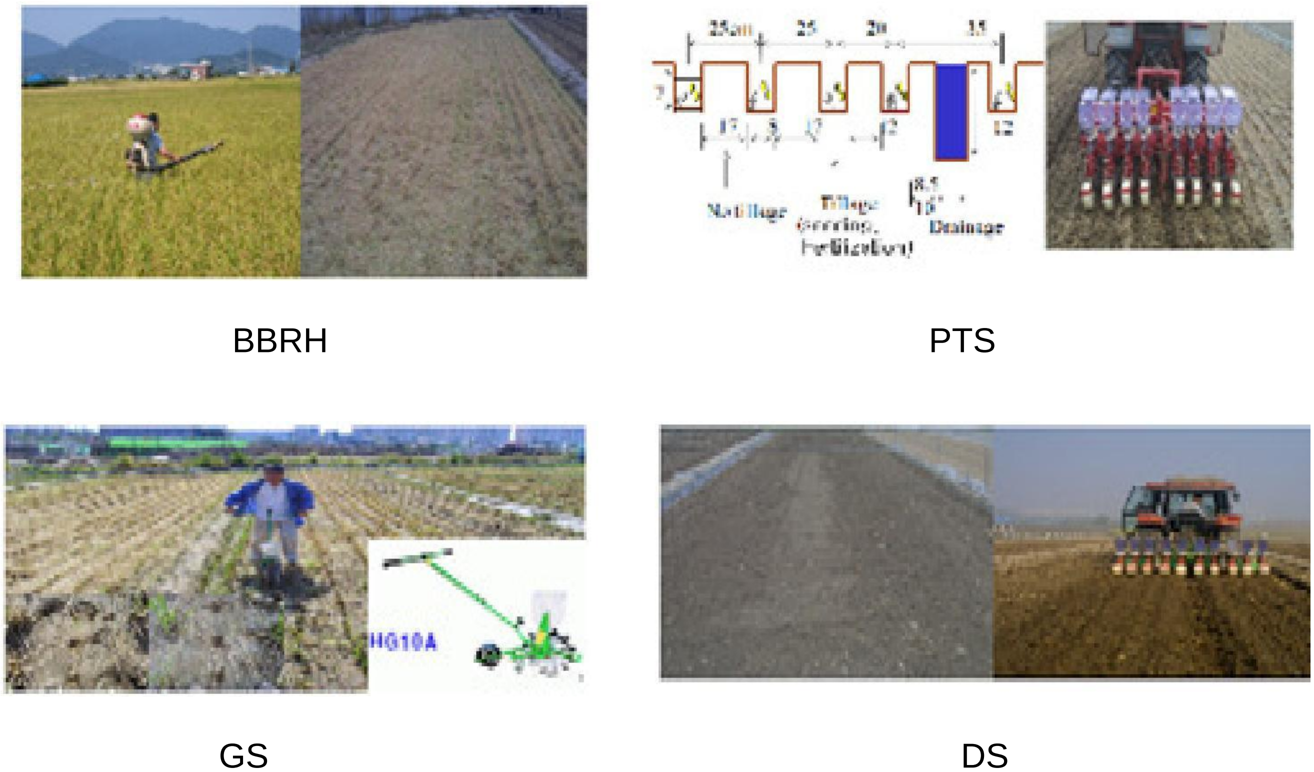

Figure 1. Seeding methods and incorporation of green manure crops for rice cultivation. Broadcasting before rice harvesting (BBRH), partial tillage seeding (PTS), group seeding (GS) and drill seeding (DS).

Soil analysis

Soil samples (15 cm) were collected from each plot after rice harvest and air dried. The soil samples were then ground to pass through a 2-mm sieve, after which they were stored in plastic zipper bags for further analysis. Selected chemical and physical properties were measured according to the standard methods of the Rural Development Administration (RDA, 1988), Korea. Specifically, soil bulk density was measured in undisturbed samples using the cores method (100 cm^3). The total porosity of the soil was calculated from the bulk density assuming a soil particle density of 2.65 Mg m^{-3} using the following formula:

Total porosity = 1- (bulk density/particle density)

For chemical analysis, the nitrate nitrogen content in soil was determined using a FIAstar5000 (FOSS Sweden) after extraction in 2 M potassium chloride solution (RDA, 1988). The soil pH was measured with distilled water using a pH meter (1:5). The soil organic carbon was measured using a mixture of potassium dichromate and concentrated sulfuric acid according to the Walkley-Black method, while nitrogen was analyzed using a CNS analyzer (Leco, USA).

Statistical analysis

Differences among treatments were estimated by one-way analysis of variance (ANOVA) using the Statistical Analysis System (SAS) program (SAS institute, ver. 9.1, 2004) with Tukey's least significant difference (LSD). Differences were considered significant at $p < 0.05$.

RESULTS AND DISCUSSION

Green manure productivity as affected by winter

Cultivation of green manure in the rice field ecosystems of several provinces in Korea has led to improved soil fertility and increased rice yield. Characteristics and cultivation techniques for winter green manure should be considered after rice harvesting. Specifically, the drainage system and climate (cold during winter) play an important role in the selection of green manure that is sown in autu-mn and grown in winter after rice harvesting. Moreover, survival of green manure during winter also plays an important role in the decision to cultivate green manure. Therefore, the biomass and growth parameters of hairy vetch and barley as green manure were studied. Plant height, number of tillers and NO_3-N were estimated after their cultivation before and after winter (Table 1). Prior to winter, the number of tillers of hairy vetch was increased significantly in DS (213.3 m^{-2}), followed by BBRH (211.1 m^{-2}) and PTS (194.4 m^{-2}) when compared to GS treat-ment (66.7 m^{-2}). No significant differences were observed among BBRH, PTS and DS treatments. Conversely, the GS treatment showed the lowest number of tillers because its seeding date was late and covering soil was not possible under the no tillage conditions. The highest plant height of hairy vetch was observed in the BBRH

Table 1. Plant height and number of tillers of green manure and soil nitrate concentration before and after winter.

Green manure crops	Seeding method	Before winter (2007-11-16)			After winter (2008-03-31)		
		Green manure		Soil	Green manure		Soil
		Height (cm)	Tiller (No.m^{-2})	NO_3-N (mg kg^{-1})	Height (cm)	Tiller (No. m^{-2})	NO_3-N (mg kg^{-1})
Hairy vetch	BBRH	24.6a	211.1a	4.19a	15.5a	186.7a	1.70b
	PTS	12.8b	194.4a	5.14a	15.2a	244.4a	1.45b
	GS	10.3b	66.7b	3.88a	15.4a	31.1c	1.68b
	DS	9.96b	213.3a	4.74a	12.1a	133.3b	2.00b
Barley	BBRH	13.3a	277.8a	2.72b	14.5a	105.6b	3.84a
	PTS	13.5a	255.6a	2.50b	17.3a	150.0b	2.07ab
	GS	2.44b	66.9b	4.01a	14.1a	44.4d	3.25a
	DS	1.56b	306.7a	3.26ab	13.7a	246.7a	2.26ab

BBRH: Broadcasting before rice harvesting, PTS: partial tillage seeding, GS: group seeding and DS: drill seeding.

treatment (24.6 cm), while no significant differences were observed among the PTS, GS and DS treatments. The number of tillers of barley showed the same trend as that of hairy vetch, with values of 306.7, 277.8, 255.6 and 66.9 being observed for the DS, BBRH, PTS and GS treatments, respectively. Moreover, the plant height of barley increased significantly in the BBRH and PTS treatments (13.3 and 13.5 cm) when compared with the DS and GS treatments (2.44 and 1.56 cm). In addition, no significant differences were observed in the nitrate nitrogen concentration in the cultivated area of hairy vetch among the tested seeding methods. The nitrate nitrogen concentration was highest in the cultivated area of hairy vetch and lowest in the cultivated area of barley, with the exception of the GS. This was primarily due to the barley, which is gramineae, absorbing more nitrate than the leguminous crops or hairy vetch, which can perform nitrogen fixation but rye use nitrate nitrogen by N mineralization into paddy soil after rice harvest (Rosecrance et al., 2000).

After winter, no significant differences in plant height were observed among the seeding methods tested for cultivation of barley and hairy vetch as green manure (Table 1). For hairy vetch treatment, the highest tiller number was observed in the PTS treatment (244.4 m^{-2}), while the lowest number was recorded in the GS treatment (31.1 m^{-2}). Additionally, no significant differences were observed between the BBRH and PTS treatment (Table 1). Moreover, the number of tillers increased in the PTS treatment after winter when compared to before winter. This was primarily attributed to PTS treatment leading to covering of the soil surface and subsequent reduction of the cold effect during winter. Moreover, a drainage channel was created and found to effectively prevent wet injury. The infiltration rate of the soil water was also rapid during a period of heavy rain in response to no-tillage treatment. Therefore, improvements in soil water retention and transmission may have provided a better environment for root development (Arshad et al., 1999; Lai et al., 2007). Overall, the results showed that the number of tillers was lower in the GS treatment for hairy vetch and barley than in the other treatment groups. This was likely due to late seeding and the soil not being covered, thereby reducing the survival of green manure during winter. Based on the results of this study, the characteristics of green manure crops showed different climate and soil drainage requirements. Vetch is considered as the most popular green manure used in southern Korea's rice fields since it is highly adaptive to the hard winter conditions and can grow well under wet paddy soil environment (Kim et al., 2007).

Green manure uniformity

The effectiveness of green manure is related to its biomass production, which is dependent on the green manure management. Similarly, the uniformity of green manure covering is an important factor for improvement of rice growth and yield following the application of green manure. Specifically, if the growth of green manure is concentrated on one side of an area, it can be a source of lodging, disease and pests that has a negative effect on rice yield. Therefore, the effect of the seeding methods before incorporation of green manure on the plant height and canopy height of green manure were investigated. The coefficient of variation (CV) of the canopy height was calculated to elucidate the uniformity of the green manure cover (Table 2). The results showed that the plant height of the hairy vetch that was sown for the first time was significantly greater in the BBRH and PTS treatments (114.1 and 101.4 cm) when compared with the GS and DS treatments (93.3 and 94.5 cm). No significant differences were observed in the plant height of barley among

Table 2. Effects of seeding methods on green manure height, canopy height and coefficient of variation before incorporation.

Green manure crop	Seeding method	Plant height (cm)	Canopy	
			Height (cm)	CV (%)
Hairy vetch	BBRH	114.1a	75.0a	12.2
	PTS	101.4b	63.6b	5.8
	GS	93.3c	75.7a	5.5
	DS	94.5c	77.5a	9.7
Barley	BBRH	71.9d	76.7a	9.6
	PTS	65.9d	70.4a	4.8
	GS	61.0d	65.5b	7.4
	DS	63.2d	68.1ab	8.0

BBRH: Broadcasting before rice harvesting, PTS: partial tillage seeding, GS: group seeding, DS: drill seeding, CV: coefficient of variation.

Table 3. Dry weight, nitrogen production and C/N ratio of green manure crops in different seeding treatments before incorporation.

Green manure crop	Seeding method	Dry weight		Green manure N production (kg ha^{-1})	C/N ratio
		Green manure kg ha^{-1}	Weed[a] kg ha^{-1}		
Hairy vetch	BBRH	5,450a	90c	165a	14.9b
	PTS	5,360a	360b	159a	15.3b
	GS	3,410c	460b	928c	17.0b
	DS	4,560b	200b	133b	15.8b
Barley	BBRH	2,250e	340b	19.9e	49.8a
	PTS	2,970d	220b	28.4d	49.3a
	GS	1,320f	1,170a	12.5e	48.5a
	DS	2,760d	220b	27.7d	46.0a

BBRH: Broadcasting before rice harvesting, PTS: partial tillage seeding, GS: group seeding and DS: drill Seeding. [a] Water foxtail.

all tested seeding methods (Table 2). The lowest plant height of the canopy was observed in PTS and hairy vetch treatment (63.6 cm). Conversely, PTS treatment increased the plant height canopy when compared to hairy vetch (Table 2). Furthermore, the coefficient of variation of the canopy height increased in the BBRH and hairy vetch treatment (12.2%) when compared to the PTS (5.8%), GS (5.5%) and DS (9.7%) groups. These results indicated that BBRH treatment decreased the uniformity of green manure, while PTS or GS was the best treatment for hairy vetch uniformity. Evaluation of the coefficient of variation of the canopy height with barley revealed that PTS treatment had the lowest value (4.8%), but was the best treatment for barley uniformity. Accordingly, if green manure crops are cultivated with PTS in paddy soil after rice harvesting, the field uniformity of covering will be improved. Based on these results, the uniformity of green manure covering plays an important role in rice production in Korean green manure-rice cultivation systems.

Green manure biomass and N-productivity

In this study, we investigated the effects of seeding methods on green manure (hairy vetch or barley) biomass and

Table 4. Effects of incorporation of green manure crops on rice yield and its components in response to different seeding methods.

Treatment	Seeding method	Panicle (no. hill^{-1})	Spikelets (no. panicle^{-1})	1,000 grain weight (g)	Ripened grain (%)	Rice yield (kg ha^{-1})
Hairy vetch	BBRH	21.1a	81.0b	20.8b	88.8c	5,330a
	PTS	21.2a	78.0b	21.6b	87.9c	5,320a
	GS	10.7b	79.0b	24.2a	84.1d	3,750c
	DS	20.0a	69.9c	21.6b	88.2c	5,140ab
Barley	BBRH	11.1b	93.4a	23.0a	90.2b	3,300c
	PTS	12.7b	78.1b	23.1b	89.0b	3,520c
	GS	9.30b	85.0ab	23.4b	89.3b	3,310c
	DS	12.3b	78.5b	22.3b	93.3a	3,080d
CF	Control[a]	19.5a	94.3a	22.6b	90.2b	5,040b

CF, Conventional fertilization; [a]without addition of green manure; BBRH, broadcasting before rice harvesting; PTS, partial tillage seeding; GS, group seeding; DS, drill seeding.

N-productivity before incorporation into soil. Specifically, the green manure dry weights, N-production and C/N ratio were investigated (Table 3). BBRH treatment resulted in a significant increase in the dry weight of hairy vetch (5,450 kgha^{-1}), followed by PTS treatment (5,360 kg ha^{-1}) when compared to DS and GS treatments (4,560 and 3,410 kg ha^{-1}). Conversely, the dry weight of barley was lower than that of hairy vetch in all treatment groups (Table 3). A similar trend was observed for N production of barley and hairy vetch. Both the dry weight and N production of barley were lower than those of hairy vetch for all seeding methods. Additionally, the occurrence of weeds (water foxtail) was greatest in the GS treatment group, in which dry matter production was the lowest (3,410 kg ha^{-1} for hairy vetch and 1,320 kg ha^{-1}for barley). In addition, the C/N ratio of hairy vetch was lower than that of barley, and there was no significant difference among the tested seeding methods (Table 3). Based on these results, the production of green manure as dry weight and N production was higher in response to the application of hairy vetch than barley for all tested seeding methods. This may have occurred because hairy vetch is a legume crop that can form root nodules and N_2-fixation. Additionally, the ability of leguminous plants to utilize P is rather strong, which leads to increased plant production. These results are in agreement with those of a study conducted by Jeon et al. (2008), who found that the production in response to green manure was greater for hairy vetch than barley. Moreover, the cultivation of green manure without the use of chemical fertilizer was better when hairy vetch, which is a legume crop, was used than when barley, which is gramineae, was used. Hartwig and Ammon (2002) reported that hairy vetch is a vigorous winter growing forage legume. Additionally, several studies have suggested that hairy vetch is one of the most efficient nitrogen-fixers and can accumulate a large amount of nitrogen during the growing period (Anugroho et al., 2009; Seo and Lee, 2008). Furthermore, hairy vetch can be used as a winter cover crop to suppress weeds and supply N for the following summer crop when applied as green manure or mulch due to its rapid subsequent N mineralization (Brandsaeter et al., 2008). In terms of seeding methods, BBRH and PTS are better based on economic feasibility, productivity and stability. Specifically, PTS treatment had similar results with that of BBRH with respect to biomass and N production (Table 3); however, the uniformity of covering and stability of the winter season in PTS were better and are therefore recommended for use as rice straw for livestock feed.

Rice yield and its components

In this study, we investigated the effect of seeding meth-ods and green manure crops (hairy vetch or barley) on yield and its components. Methods of seeding signifi-cantly influenced the yield of rice (Table 4). Specifically, the rice yield was increased significantly in the BBRH (5,330 kg ha^{-1}) and PTS (5,320 kg ha^{-1}) treatments and when hairy vetch was used as green manure when com-pared to conventional fertilization (Table 4). This likely occurred because the BBRH and DTS treatments also showed significantly higher numbers of panicles per hill when compared to conventional fertilization. No signifi-cant difference was observed between the DS treatment and conventional fertilization groups. Conversely, GS treatment led to a significant decrease in rice yield when compared to conventional fertilization. Moreover, all of the tested seeding methods and the use of barley as green manure led to a significant decrease in rice yield when compared to conventional fertilization. The yield compo-nents (spikelets per panicle, ripened grain and 1,000 grain

Table 5. Effects of seeding methods of green manure crops on soil physical and chemical properties.

Green manure crop	Seeding method	Soil porosity (%)	Bulk density (Mg m^{-3})	pH (1:5)	TN (%)	O.M (%)
Hairy vetch	BBRH	56.6	1.15	5.04	0.14	3.14
	PTS	58.7	1.09	5.40	0.17	3.28
	GS	52.0	1.27	5.32	0.13	3.07
	DS	52.8	1.25	5.80	0.14	2.68
Barley	BBRH	54.1	1.22	5.05	0.14	3.11
	PTS	52.8	1.25	5.05	0.17	3.25
	GS	56.5	1.15	5.27	0.13	3.10
	DS	51.5	1.29	5.13	0.15	2.89
CF	Control[a]	52.8	1.26	5.09	0.14	3.13

BBRH: Broadcasting before rice harvesting, PTS: partial tillage seeding, GS: group seeding and DS: drill seeding. CF: conventional fertilization; [a] without addition of green manure.

weight) were also lower in all tested seeding methods when hairy vetch was used as green manure when compared to conventional fertilization (Table 4). Conversely, BBRH treatment led to a significant increase in 1,000 grain weight when applied in conjunction with barley as green manure when compared to conventional fertilization. No significant differences in 1,000 grain weight among the PTS, GS and DS treatments and conventional fertilization were observed. Based on these results, BBRH and PTS treatment and the use of hairy vetch as green manure increased the rice yield when compared to the control or the use of barley as green manure. This was likely due to the high level of nitrogen (110 kg N ha^{-1}) in the hairy vetch that was applied to the soil during rice cultivation. Furthermore, the fresh weight of the applied hairy vetch was 20 ton ha^{-1} and it contained a high amount of nitrogen. Therefore, the addition of hairy vetch as green manure gave a higher yield than the conventional treatment or barley treatment (Jeon et al., 2008; Lee et al., 2010). Broadcasting prior to rice harvesting or no tillage allows crop residues to remain on the soil surface after harvest if suitable drills are available. Additionally, farmers do not have to burn residues to prepare land for the next crop. No tillage is also a viable management strategy to improve soil quality that leads to high production, minimal negative environmental impacts and a socially-acceptable farming system (Arshad et al., 1999).

Soil properties

The cultivation of green manure crops is considered to be a good management practice that increases soil organic matter and fertility levels. This experiment was conducted to investigate the effects of hairy vetch and barley applied as green manure and different seeding methods on soil chemical and physical properties after cultivation of rice. Specifically, soil porosity, bulk density, soil pH, total N and the soil organic content were evaluated (Table 5). The differences between treatment effects on soil physical characteristics were confined to the effects of the seeding method on soil porosity and bulk density in the BBRH and PTS treatments. BBRH and PTS treatments and application of incorporated hairy vetch as green manure led to decreased bulk density (1.15 and 1.09 Mg m^{-3}) when compared to conventional fertilization treatment (1.26 Mg m^{-3}). Conversely, BBRH and PTS led to increa-sed soil porosity (56.6 and 58.7%) when compared to conventional fertilization (52.8%). In addition, the application of barley as green manure caused a slight decrease in bulk density when compared to conventional fertilization, except for in the DS treatment, the bulk density was increased. These results are in agreement with those of a study conducted by Jeon et al. (2008), who found that the soil bulk density and porosity ratio were improved in the top soil after the addition of green manure. Furthermore, soil physical properties were improved after rice cropping in conjunction with the application of green manure. Arshad et al. (1999) reported that soil water retention was greater under no tillage than under conventional tillage, even though there was no dramatic alteration in the soil bulk density. These findings were primarily attributed to the redistribution of pore size classes into more small pores and less large pores.

The soil chemical properties also improved in response to the treatments and the incorporation of green manure (Table 5). Specifically, soil pH increased in the PTS (5.40), GS (5.32) and DS (5.80) treatments when hairy vetch was applied as green manure when compared to conventional fertilization (5.09). Similarly, the incorporation of hairy vetch and barley as green manure resulted in increased soil organic matter content in the PTS treatments when compared to conventional fertilization (Table 5). Furthermore, total N was slightly higher in the PTS treatment after incorporation of hairy vetch or barley when compared to the control. The nitrogen content and C/N ratio of green manure (hairy vetch or barley) is an important factor that can contribute to an increase in soil pH during decomposition and the release of OH^- ions during ammonification (Haynes and Mokolobate, 2001). Based on the results of this study, soil quality can be improved by green manure cultivation under a rice-based cropping system.

Conclusion

Green manure cultivation is a promising technology for the reduction of chemical fertilizers and herbicides in rice paddy soils in Korea. Field experiments were conducted to evaluate the effects of different seeding methods on the biomass and N production of hairy vetch and barley, and rice yield. The results showed that BBRH and PTS treatments led to a greater increase in hairy vetch biomass and N production than barley. Furthermore, BBRH and PTS led to a significant increase in rice yield and its components, specifically in the hairy vetch treatment. Hairy vetch green manure also improved soil physical properties such as soil bulk density and porosity. Based on these results, the application of hairy vetch as a winter cover crop can lead to an important reduction in chemical input with respect to nitrogen fertilization. Overall, these results indicate that hairy vetch applied together with the proper seeding method has the potential for use as a green manure crop under Korean conditions.

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