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Agronomic Characters and Soil Nitrogen Dynamics Influenced by Barley Straw Mulch Rates in No-Tillage Direct Seeding Rice Culture

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ABSTRACT

In rice-barley cropping systems, efficient utilization of barley straw is essential, both to improve the soil fertility and to conserve the environment. In order to identify the effects of barley straw mulch rates in rice cultivation, a rice cultivar, 'Gancheogbyeo', was directly seeded on a no-tillage field synchronized with barley harvesting with five barley straw mulch rates, i.e., 0, 2.5, 5.0, 7.5 and 10.0 ton ha^{-1}, and agronomic characters of rice and soil nitrogen were determined. The increasing of barley straw mulch rates. Dominant weed species, chestnut, occurred in large amounts in no mulching or lower mulch rates than in higher mulch rates. The content of NH_4^+-N in soil applied with high barley straw mulch rates was lower during the month after seeding, and then it was higher at heading date, compared with lower mulch rates or no mulch plot. As the barley straw rate increased, maximum tillering stage was delayed, and plant height was reduced. Although the lodging of rice plants was seldom observed in all plots, the breaking strength of the culm was significantly higher in the mulch rate of 10.0 ton ha^{-1}. With an increase of barley straw mulch rate, the effective tillering rate and spikelet number m^{-2} decreased while ripened grain ratio increased. The rice grain yield was slightly decreased with an increase of barley straw mulch rate, although significant differences were not found all barley straw mulch rates. These results suggest that there is no significant yield loss although the total barley straw production, approximately 5.0 ton ha^{-1} in the present study, apply in the paddy for the following rice cultivation by no-tillage direct seeding.

Keywords : rice-barley cropping, rice, barley straw, direct seeding, no-tillage nitrogen.

Rice-barley cropping in paddy fields is one of most important cultivation systems for improving land utilization and food self-sufficiency in Korea, but the area of rice-barley cropping is less than 10% of the total paddy fields (Park & Ha, 1998). The reason is the rice yield in rice-barley cropping systems is usually reduced by delayed rice transplanting and the income gained from the barley crop is relatively less than that from other horticulture crops cultured during the winter season. Thus, farmers presently tend to avoid barley culture. Therefore, the development of rice and barley cropping methods with cost reduction and yield stability is important for the enlargement of the rice-barley cropping area.

In the rice-barley cropping system, the raised rice seedlings are commonly transplanted after the barley harvest and field tillage, which are concentrated in June. Rice cultivation by no-tillage direct seeding synchronized with barley harvesting using a combine with a drill seeder attached was considered a remarkable method that could reduce tillage, puddling, seedling raising and transplanting (Irie et al., 1987; Kim et al., 1995; Choi et al., 1999). In the no-tillage rice direct seeding synchronized with barley harvesting system, barley straw production is returned to the paddy field after mechanically cutting by a combine and inevitably covering the direct sown rice seeds.

On the other hand, the traditional recommendation is to return barley and rice straw to the paddy field as an organic matter source in rice production systems throughout the world (Lee & Hwang, 1984; Shin & Shin, 1975; Yoneyama & Yoshida, 1977; Yoshida & Padre Jr., 1975). Applied barley or rice straw, however, sometimes cause a decrease in the early growth and grain yield of rice mainly due to the toxicity of organic acids produced from straws (Chandranekaran & Yoshida, 1973; Moroyu et al, 1981; Rao & Mikkelsen, 1976). Recently, it is a concern that the soil fertility tends to declin by either increasing amount of fertilizers or decreasing organic matter application. Therefore, the efficient utilization of barley straw is essential to maintain soil fertility and rice productivity. The straw mulch on fields can not only reduce runoff volume containing the nutrient or sediment losses (Shock et al., 1998), but also to prevent the production of greenhouse gases caused by straw burning, which is commonly done in rice-barley cropping system in Korea.

Despite a number of researches on barley straw application in rice cultivation (Cheong et al., 1997;

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Morita et al., 1984; Moroyu et al., 1981; Irie et al., 1987), information on both proper barley straw mulch rate and rice growth effects by applied barley straw are not available for the no-tillage rice direct seeding. Objective of the study was to clarify the responses on seedling stand, growth and yield of rice, and changes of NH_4^+-N content in paddy, according to application of different barley straw rates on no-tillage direct seeding.

MATERIALS AND METHODS

Direct seeding of rice

For the present study, 'Ganchegbyeo' a medium maturing rice cultivar, was selected as an adaptable cultivar for no-tillage rice direct seeding with superior characteristics on both seedling establishment and yield from the result of previous study (Choi, 1999). A field experiment was conducted on a silty loam soil at paddy field of National Honam Agricultural Experiment Station (NHAES), Rural Development Administration (RDA) in 1995. Prior to the rice culture, a barley cultivar 'Songhakbori' was grown on that field with 1.2 m in row width and 0.9 m in seeding width. At seeding date, soil test values at 5-10 cm soil layer were pH(1:5) = 5.7, organic matter = 2.7%, total nitrogen = 0.07%, and available P_2O_5 = 86 ppm. In addition, exchangeable K, Ca and Mg were 0.24, 6.6 and 2.4 c mol kg^{-1}, respectively.

On June 14, dried rice seed sterilized with prochloraz was directly sown at a depth of 3 cm with 25 cm row spacing at the rate of 80 kg ha^{-1} on a no-tillage field using a drill seeder attached to a combine and synchronized with barley harvesting. All the barley straw mechanically cut in 5~15 cm lengths by the combine was gathered. The total barley straw was weighed and divided by the harvested field area. The mean barley straw yield was about 5 ton ha^{-1}. Thus the regimes of barley straw mulching were classified into five rates, 0, 2.5, 5.0, 7.5, and 10.0 ton ha^{-1}, and mulched by hand on the rice seeded field. The area per plot was 24 m^2 (2.4 × 10.0 m), and the plots were arranged in a randomized block design with three replications.

Rice culture

Nitrogen fertilizer at the rate of 110 kg ha^{-1} was applied in a split application of 40 : 30 : 30% at just after seeding, tillering and panicle formation stage, respectively. Phosphorus fertilizer at the rate of 70 kg ha^{-1} was totally applied just after seeding. In addition, potassium fertilizer of at the rate of 80 kg ha^{-1} was applied at a split rate of 70 : 30% at just after seeding and the panicle formation stage, respectively.

The first flooding was done by flush irrigation just after seeding and barley straw mulching. One day after irrigation, the plots were drained and the field moisture capacity was sustained to promote seedling emergence. From the 3rd leaf stage, the rice plants were cultured under flooding condition.

The herbicide dimepiperate bensulfuron-methyl at a rate of 2.14 kg a.i. ha^{-1} was used for weed control at the 3rd leaf stage except the investigation sites for weed occurrence. Bentazone at the rate of 1.6 kg a.i. ha^{-1} was sprayed to suppress the perennial weeds at 30 days after seeding (DAS). Other management practices followed the standard practices at NHAES.

Data collection

The number of rice seedlings was determined in a 2 rows by 1 m area (0.5 m^2) per plot at the 3rd leaf stage. At 30 DAS all weed plants were collected in a 6 m^2 sample area per plot without treatments for weed control, and were classified into species. Upon drying, the weed samples were weighed. Soil samples for analysis of NH_4-N were collected at 6 sites in the 5-10 cm soil layer at 35, 45, 55 DAS, heading stage and 30 days after heading (DAH). After extracting in 10% KCl solution, NH_4-N was determined by colorimetric procedures using a spectrophotometer (Uvikon, Kontron Inc., Italy). Culm number and plant height were quantified from randomly sampled 10 hills per plot 6 times from 20 DAS to the heading stage. Plant samples for the analysis of total nitrogen were collected at 40 days after heading and dried in 80°C oven condition for 48 hours and then weighed. After milling the plant samples, total nitrogen was measured using the Auto Nitrogen Analyzer (Alpkem 3550, Alpkem Co., USA). Agronomic characters related to lodging were determined at 20 DAH. The culm breaking weight was measured at the 4th internode with 6 cm distance between two fulcrums using a dial gage (Kiya, Co., Japan). The degree of field lodging was recorded on the scale of 0 (none) to 9 (severe lodging) at 30 DAH. At 45 DAH, the rice was harvested in 3 m^2 per plot, and the yield and yield components were determined following the method of RDA (1995).

RESULTS AND DISCUSSION

Rice seedling stand and weed occurrence

The number of seedlings m^{-2} in no-tillage rice direct seeding varied with the rates of barley straw mulch applied (Table 1). The number was highest in the no mulch plot with 275 m^{-2} and was significantly reduced with an increase of barley straw mulch rate. Thus, it showed the lowest number of 147 m^{-2} at the barley straw mulch rate of 10.0 ton ha^{-1}. This tendency of a decrease of seedling stand due to the increase of barley straw mulch rate also showed in the previous study, although it was conducted by scatter seeding before barley harvest (Cheong et al., 1996, 1997). Although the proper number levels in water direct seeding varies by weather conditions and location, its range in the plaine area of Honam district was 80-120 m^{-2} for a normal season and 110-140 m^{2} for late season, respectively (Kim, 1996; Song et al., 1995). In the present study, the number of seedlings in all plots was higher than the above mentioned case of late season when it was seeded in early June. The higher number of seedling stand in this study was possibly caused not only by the higher seeding rate and higher temperature than those in previous studies, but also the difference in water management after seeding. On the other hand, our previous study (Choi, 1999). Using pregerminated seeds showed lower seedling stand numbers, particularly in heavy barley straw mulch compared with the present study using non-pregerminated seeds. These results suggest that the seeding of non-pregerminated seeds and the management technique of draining upon flooding for one day after seeding would be recommended for improving the seedling stand in no-tillage direct seeding with straw mulching.

During the early rice growth stage, chestnut (*Eleocharis kuroguwai* O.) was most dominant weed species and barnyard grass (*Echinochloa crus-galli* B.) was also observed in a few levels. Biomass of both weeds was significantly highest in the no-mulch plot and decreased with an increase of barley straw mulch amount. Therefore, barley straw mulching in no-tillage rice direct seeding has the advantage of suppressing weed emergence during the early growth stage.

The above mentioned results imply that the higher barley straw mulch rate may have increased the physical resistance and interception of sunlight radiation, thus reducing the rice seedling stand and weed occurrence in those plots.

Table 1. Number of rice seedling stand per m^2 and weed occurrence at 30 days after seeding under different rates of barley straw mulching in no-tillage rice direct seeding culture.

Barley straw mulch rates (ton ha^{-1})	No. of rice seedling stands per m^2	*Eleocharis kuroguwai* O. ($g\ m^{-2}$)	*Echinochloa crus-galli* B. ($g\ m^{-2}$)
0	275a†	2.61a	0.16a
2.5	228b	1.75b	0.09b
5.0	215b	1.62b	0.09b
7.5	203b	1.61b	0.09b
10.0	147c	0.69c	0.06b

† Means followed by different letters are significantly different at 5% level of probability by DMRT.

Soil N dynamics and plant N uptake

Dynamics of NH_4^+-N content at the 5~10 cm soil layer with different growth stages are presented in Fig. 1. There were marked differences in the changing pattern of soil NH_4^+-N among the barley straw mulch rates. At 35 DAS, the NH_4^+-N levels were highest at no mulch and decreased with an increase of mulch rates. During the 35 DAS to 45 DAS, the NH_4^+-N level declined rapidly in no mulch, and other plots also tended to decline slightly. During 55 DAS to heading stage, the NH_4^+-N levels increased in heavy barley straw mulch (over 5.0 ton ha^{-1}) and then declined to the maturing stage. At the heading stage, therefore, the NH_4^+-N levels were higher in order of increased rate of barley straw mulch and lowest in no mulch. These dynamic patterns of NH_4^+-N content in soil was similar to previous reports of paddy fields applied with barley straw (Moroyu et al., 1981) and rice straw (Lee & Hwang, 1984; Yoshida et al., 1975).

Nitrogen content in the plant increased during 35 DAS to 55 DAS, and then declined to the maturing stage (Table 2). At 55 DAS the nitrogen content in the plant was highest in no barley straw mulch and lower in order of increasing barley straw mulch amount, while it was not significantly different at 40 DAH. Nitrogen uptake rate per unit area at 40 DAH was highest in the barley straw mulch rate of 2.5

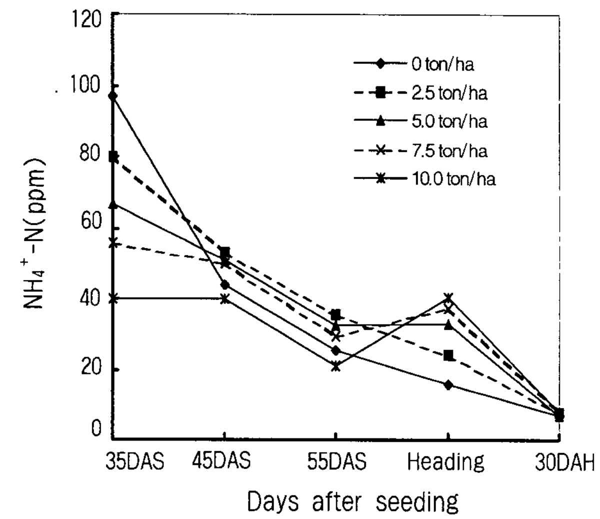

Fig. 1. Changes of NH_4^+-N concentratio in soil with rice growth stage under different mulch rates of barley straw in no-tillage direct seeding.

Table 2. Changes of nitrogen content in rice plant, total dry weight and nitrogen uptake at 40 DAH according to different mulch rates of barley straw in no-tillage direct seeding.

Barley straw mulch rates (ton ha^{-1})	N-content in plant (%)				Total shoot dry weight at 40 DAH (g m^{-2})	N-uptake at 40 DAH (g m^{-2})
	35DAS†	55DAS	HD‡	40DAH§		
0	3.57	4.10	2.50	1.46	1,240	18.1
2.5	3.49	3.97	2.59	1.49	1,304	19.4
5.0	3.42	3.88	2.42	1.47	1,246	18.3
7.5	3.42	3.68	2.42	1.47	1,163	17.1
10.0	3.41	3.24	2.33	1.45	1,094	15.9

† DAS : days after seeding, ‡ HD : heading date, § DAH : days after heading.

ton ha^{-1}, and was lower in mulch rates of 7.5 and 10.0 ton ha^{-1}. The difference in nitrogen uptake rate per unit area at 40 DAH may have resulted from differences in shoot dry weight.

Plant growth

There was a trend of reduced plant height due to an increase of the barley straw mulch rate during all growth stages (Fig. 2A). Until the maximum tillering stage, the number of tillers was lower in plants with an increase of barley straw mulch rate. The maximum tiller stage was reached at 35 DAS in no mulch and barley straw mulch rate of 2.5 ton 10 ha^{-1}, while at 45 DAS in other plots (Fig. 2B). At the heading stage, the number of tillers was orderly decreased with an increase of barley straw mulch rate. The effective tiller rate was the least in the no mulch plot at 63.9%, while it ranged from 70.5 to 72.5% in barley straw mulch plots (Table 4). As shown in Fig. 1 and discussed by Moroyu et al. (1981), plant growth was reduced at the early growth stage due to an increase of barley straw application amount, and from the lower content of NH_4^+-N in soil due to an increase of organic nitrogen content in soil.. The plant growth tended to recover at the mid-late growth stage due to an increase of inorganic nitrogen content in the soil.

Lodging and lodging related characters

Agronomic characters related to lodging and the lodging index of rice plants at 20 DAH were shown in Table 3. Most of the characters and the lodging indexes were quite similar among all mulch rates except the rate of 10.0 ton ha^{-1}, where it tended to be lower in culm length and height of gravity center but significantly greater in shoot fresh weight, shoot mo-

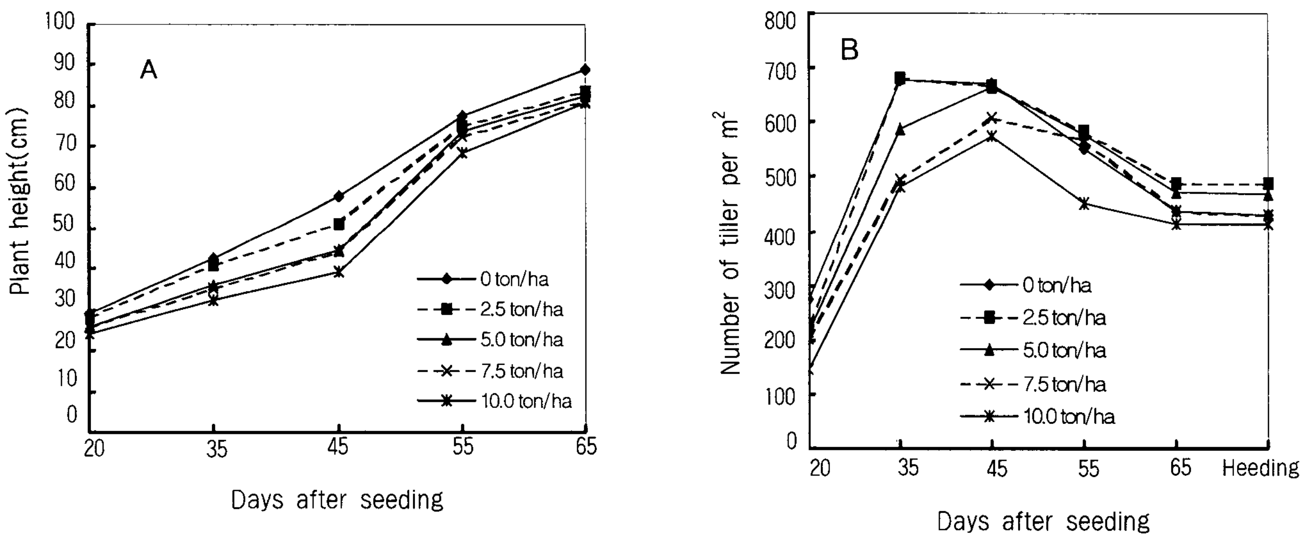

Fig. 2. Changes in plant height and number of tillers per m^2 of rice with days after seeding under different mulch rates of barley straw in no-tillage direct seeding
I : Vertical bars in graphs indicate the size of LSD (5%) values.

Table 3. Field lodging and agronomic characters related with lodging in direct seeded rice on no-tillage according to different barley straw mulch rates.

Barley straw mulch rates (ton ha^{-1})	Culm+ panicle length (cm)	Height of center gravity (cm)	Shoot fresh weight (g)	Shoot moment (g · cm)	Culm diameter† (mm)	Culm wall thickness† (mm)	Breaking weight† (g)	Lodging index	Field lodging (0-9)
0	91.9	41.9	8.8	809	3.5	0.72	451	179	1
2.5	91.4	40.9	8.7	795	3.4	0.63	468	170	1
5.0	90.4	40.6	8.7	786	3.3	0.63	427	184	1
7.5	88.1	40.4	8.5	749	3.3	0.61	407	183	1
10.0	88.0	39.5	9.9	871	3.6	0.70	538	161	1
L.S.D.(5%)	4.5	3.1	1.0	78	0.5	0.12	85	30	
C.V.(%)	1.8	2.7	4.0	3.5	5.2	6.4	6.6	6.2	

† 4th internode from panicle node.

Table 4. Difference of yield and yield components by barley straw mulch rates in rice culture by no-tillage direct seeding.

Straw mulch rates (ton ha^{-1})	Heading date	Effective tiller rate (%)	No. of panicle per m^2	Spikelet no. per panicle	No. of spikelet per m^2 (×1,000)	Ripened grain (%)	1,000 grain weight (g)	Milled rice yield (ton ha^{-1})	Yield index
0	Aug. 29	63.9	453	63	28.3	87	22.5	4.60	100
2.5	Aug. 29	71.8	488	58	28.5	85	22.5	4.60	100
5.0	Aug. 29	70.5	469	58	27.4	86	22.5	4.55	99
7.5	Aug. 29	70.8	431	59	25.3	88	22.5	4.46	97
10.0	Aug. 29	72.5	416	59	24.4	90	22.1	4.37	95
L.S.D.(5%)	-	16.5	70	4.2	-	3.6	0.4	0.34	
C.V.(%)	-	12.4	4.7	3.8	-	2.2	2.0	4.8	

ment, culm diameter and the breaking weight of culm base. Therefore, the lodging index was lower in the straw mulch rate of 10.0 ton ha^{-1} which was mainly due to the characteristics of shorter plant height and thicker and stronger culm compared to those of other mulch rates. In addition, the degree of lodging in the field at maturing stage was not different among all treatments. Consequently, the possibility of lodging occurrence in no-tillage rice direct seeded with barley straw mulching is relatively lower than that of normal season culture, due mainly to shorter plant height.

Yields and its components

There was no delay observed in the heading date due to barley straw mulching (Table 4). Panicle number m^{-2} was highest in the barley straw mulch rate of 2.5 ton ha^{-1} and significantly reduced at 10 ton ha^{-1} compared to 2.5 ton ha^{-1}. The spikelet numbers per panicle was higher in the no mulch plot than in mulch plots where the difference was not showed among the mulch rates. Number of spikelets m^{-2} was highest in the barley straw mulch rate of 2.5 ton ha^{-1} with 28,500 spikelets and orderly decreased by increasing of mulch rate, thus it showed 24,400 spikelets at the mulch rate of 10.0 ton ha^{-1}. In contrast, the percentage of ripened grain was least in the barley straw mulch rate of 2.5 ton ha^{-1} and slightly increased with an increase of mulch rate. Although the milled rice yield was not significantly different among the mulch rates, it was slightly decreased in the mulch rates of 7.5 and 10.0 ton ha^{-1} where yield indexes were 97 and 95 compared with no barley straw mulch plots, respectively. The difference among barley straw mulch rates in rice yield can be particularly attributed to differences in number of panicles per unit area, which are also mainly influenced by the number of seedling stand per unit area. Contrary results were previously reported that with an application of barley straw, the rice yield was slightly increased (Kim & Shon, 1983), while the yield was decreased for the first or second year, but it was increased in the third year after continuously applying barley straw (Moroyu et al., 1981).

In conclusion, the results of the present study suggest that mulching of all the barley straw production in a field, approximately 5.0 ton ha^{-1} in the present study, can be recommended in no-tillage direct seeding for improving soil fertility with little yield loss.

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