RESEARCH ARTICLES
J. Crop Sci. Biotech. 10 (2) : 79 ~ 85

Rice Bran Application under Deep Flooding Can Control Weed and Increase Grain Yield in Organic Rice Culture

Yong-Feng Yan[1], Jin-Dong Fu[1], Byun-Woo Lee[1,*]

[1]*Department of Plant Science, Seoul National University, Seoul 151-921, Korea*

Abstract

Rice bran application just after transplanting has been increasingly practiced as a herbicide-substitute for organic rice production in Korea. However, this practice is frequently reported to be unsatisfactory in weed suppression. An experiment with five treatments that combine flooding depth (shallow and deep), rice bran application level (low and high), and herbicide application was carried out in the paddy field to evaluate whether rice bran application under deep flooding can lead to successful weed control in compensation for the single practice of rice bran. Rice bran was broadcasted on the flood water surface just after deep flooding of 8 to 10 cm that was started at seven days after transplanting. Six weed species were recorded in the shallow flooding plot without herbicide: *Monochoria vaginalis, Echinochloa crus-galli, Ludvigia prostrate, Cyperus amuricus, Aneima keisak, and Bidens tripartite.* Among the first four dominant weed species, deep flooding significantly suppressed the occurrence of *Echinochloa crus-galli* and *Cyperus amuricus*, while it did not suppress the occurrence of *Monochoria vaginalis* and *Ludwigia prostrate*. On the contrary, rice bran application under deep flooding significantly suppressed *Monochoria vaginalis* and *Ludwigia prostrate*, while didn't exert an additional suppression of *Echinochloa crus-galli* and *Cyperus amuricus* compared to deep flooding alone. Rice bran application and deep flooding suppressed complimentarily all six weed species to a satisfactory extent except for *Monochoria vaginalis* for which suppression efficacy was 31.9%. Deep flooding substantially reduced the panicle number by inhibiting the tiller production, increased the spikelet number per panicle slightly, and led to a lower rice grain yield compared to shallow flooding with herbicide. Rice bran application under deep flooding mitigated the panicle reduction due to deep flooding, increased the spikelets per panicle significantly, and thus produced even higher grain yield in the rice bran application of 2000 kg ha^{-1} as compared to the shallow flooding treatment with herbicide. In conclusion, it would be advisable to implement rice bran application under deep flooding as an integral practice for an organic rice farming system.

Key words: rice, rice bran, deep flooding, weed suppression, grain yield, compost

Introduction

The conventional farming systems that have relied on heavy input of agrochemicals and pursued high productivity have provoked poignant problems such as escalated production costs, heavy reliance on non-renewable resources, reduced biodiversity, water contamination, chemical residues in food, soil degradation, and health risks to farm workers handling pesticides (Drinkwater et al. 1998; Matson et al. 1997; Tillman 1999). With increasing interest in sustaining economically-viable crop production with minimal environmental impacts, organic farming without synthetic fertilizers and pesticides has been increasingly adopted as an alternative agricultural practice (Kirchmann and Thorvaldsson 2000; Reganold et al. 1993). Despite concerns on the sustainability and profitability of organic farming systems (Avery 1999; Trewavas 1999), the organic food industry is one of the fastest growing businesses (Greene 2000; Kirchmann and Thorvaldsson 2000) because market and social forces have created price premiums on a wide variety of organic foods (Reganold et al. 2001). Organic rice farming has also been rapidly adopted in response to increasing customer demands and government policy initiatives in Korea (MAF 2005). Weed management is a very important and labor-intensive practice in organic farming systems compared to conventional methods utilizing herbicide. Ducks, golden apple snail (GAS) and rice bran have

* **To whom correspondence should be addressed**
Byun-Woo Lee
E-mail: leebw@snu.ac.kr
Tel: +82-2-880-4544

been widely adopted for biological weed control in organic rice farming in Korea (MAF 2005). Duck-rice farming is known to be very effective for controlling paddy weeds except for *Echinochloa crus-galli*. However, duck-rice farming raises the farming expenses by 54-77% compared to conventional rice farming since duck breeds and feed should be purchased, and it is not easy to sell the ducks after rice farming (Cho et al. 1999). So, duck-rice farming is gradually forsaken by Korean farmers (MAF, 2005). GAS-rice farming also has the problem of expenses and sales. Furthermore, there is widespread concern of the possibility that GAS, known as a dreaded pest of the rice plant and other aquatic crops in the tropics (Jochi R.C. et al. 2005), could over-winter in the Korean climate and imperil the agricultural environment. Compared with the above biological weeding methods, rice bran farming applied on flood water early after rice transplanting is easier to practice and adds little extra costs as it is a byproduct of rice farming (Kim et al. 2001). Thus, rice bran farming is being increasingly adopted by rice farmers to replace other organic rice farming methods (MAF 2005).

Rice bran, a byproduct of the rice milling industry, is obtained by the abrasive milling of brown rice to remove the outer tissues in order to produce the polished rice (Juliano and Bechtel 1985). Even though rice bran farming has been increasingly adopted in farmer's fields, only a few studies have addressed the potential use of rice bran for paddy weed control and soil amendment (Kim et al. 2001; Kuk et al. 2001). Kuk et al. (2001) reported that the aqueous extracts of rice bran could suppress the germination and early growth of some paddy weeds; the aqueous extracts of rice bran significantly inhibited the germination and early growth of *Eclipta prostrate even* at the low concentration of the extract but *Echinochloa crus-galli* to a much lesser extent. Kim et al. (2001) reported that rice bran application under shallow flooding conditions suppressed the occurrence of *Scirpus juncoides, Monochoria vaginalis*, and *Cypenus serotirus* substantially but not the occurrence of *Echinochloa crus-galli*. Considering the reported results, it is likely that the unsatisfactory cases have occurred frequently in rice bran farming of farmers as rice bran application alone does not have sufficient suppression effect on some weed species. In general, weed population density and total dry weight per unit area decrease as water depth increases (Bhagat et al. 1996; Catizone 1983; Moody et al. 1986; Mukhopadhyay 1983). Also, many weeds do not germinate under flooded conditions (Yamada 1959). The increased submergence up to 15 cm was reported to reduce the germination and growth of *Echinochloa crus-galli* and *Leptochloa spp.* (Bhan 1981; Raju and Reddy 1987), and flooding over 10 cm depth at the first-leaf stage almost completely suppressed the growth of *Echinochloa crus-galli* and *E. praticola* (Kwon et al. 1996). On the other hand, emergence and survival of some weeds, for example *Monochoria vaginalis*, remained unaffected by deep flooding (Bhan 1983; Pons 1982; Raju and Reddy 1987; Sahid and Hossan 1995).

As reviewed above, rice bran application and deep flooding seemed to have complimentary suppression effects on some weed species; the deep flooding suppresses the occurrence of *Echinochloa crus-galli* effectively but not the occurrence of *Monochoria vaginalis*, and vice versa for the rice bran application. Therefore, rice bran application in combination with deep flooding would be expected to have a greater chance of successful weed control. The present study aimed to confirm this possibility in weed control and evaluate the influence on yield performance in organic rice farming system employing rice bran application under deep flooding management.

Materials and Methods

This experiment was conducted at the Experimental Farm of Seoul National University at Suwon, Korea in 2005. The experimental field had a soil texture of sandy clay loam, pH of 5.4, CEC of 12.7 $cmol^+ kg^{-1}$, O.M of 20.2 $g kg^{-1}$, total N of 11.6 $g kg^{-1}$, and available P of 35.8 $mg kg^{-1}$.

Five treatments combining flooding depth, application dose of rice bran, and herbicide use included (1) shallow flooding of 3 to 5 cm and no weeding (SF, control), (2) deep flooding of 8 to 10 cm and no weeding (DF), (3) shallow flooding of 3 to 5 cm and herbicide application (SF+HB), (4) deep flooding of 8 to10 cm and rice bran application of 1000 kg ha^{-1} (DF+LRB), and (5) deep flooding of 8 to 10 cm and rice bran application of 2000 kg ha^{-1} (DF+HRB). The experiment was laid out in a randomized block design using three replications. Each plot size was 2 m × 7.5 m. An auto-water-supply system equipped with a ball cork in each plot was used to keep the flooding depth constant. To prevent side-seepage between plots with different flooding and fertilization regimes, corrugated plastic sheets were installed down to a depth of 30 cm, which was well below the top of hardpan.

The experimental field was fertilized with the compost (fermented from a mixture of swine dung, sawdust, plant residue, and zeolite, and containing 31.5% of O.M., 1.36% of T-N, 0.51% of P_2O_5, 0.27% of K_2O) of 12,000 kg ha^{-1} that is equivalent to 130 kg N ha^{-1}, plowed, and puddled three days before transplanting. Rice seedlings grown for 30 days were transplanted with machine transplanter at a spacing of 15 cm × 30 cm on 27th of May in 2005. For the deep flooding plots, deep irrigation was started at seven days after transplanting (DAT) and lasted for 30 days. Except for the deep flooding period, water level was kept at 3 to 5 cm depth as in the shallow flooding treatments. In the case of plots with rice bran application, rice bran was broadcasted manually on the flood water surface at 7 DAT. The total N, P, and K content of rice bran used in the present experiment were 3.1, 2.7, and 1.9%, respectively. The fermented compost of 3,000 kg ha^{-1} was topdressed additionally at 55 DAT.

The weeds within the quadrat of 500 cm^2 were sampled at three locations of each plot at 40 DAT and the number of weeds was recorded by species. The weed suppression efficacy was calculated as follows:

Weed suppression efficacy (%) = (WNcont - WNtreat)/WNcont × 100, where WNcont and WNtreat refer to the number of weeds in the control (shallow flooding and no herbicide treatment) and in each treatment, respectively.

The dissolved oxygen (DO) of flood water was determined and the redox potential (Eh) at 2 cm below soil surface was measured with dissolved oxygen meter (25D, Istek, Korea) and ORP meter (75P, Istek, Korea), respectively, every 2 days after deep flooding until 30 DAT.

Every 3 days after rice bran application, soil samples were collected at 0-15 cm depth by an auger from each plot. Soil samples were stored in the deep freezer of -20 ℃ for the analysis of mineral nitrogen. Ammonium and nitrate were determined on wet samples of 3 g that were extracted with 30 mL of a 2M KCl solution, filtered through filter paper, and analyzed with N/P Flow Injection Analizer (FIAstar 5000, Tecator, Sweden).

Tiller per hill were recorded from 20 hills randomly selected in each plot every two weeks after transplanting. At harvest, three hills per plot were sampled to measure dry weight and plant nitrogen concentration. Additionally, three hills for measuring yield components and 72 hills for grain yield were sampled from each plot. For measuring the plant nitrogen concentration, plant samples were dried at 65 ℃ for 72 hours. The dry samples were weighed for dry weight and ground for N analysis with Kjeltec Auto 1035 System (Tecator, Sweden).

Statistical analysis for ANOVA, LSD for mean separation, and correlation were performed using SAS 8.1 (SAS Inc. USA).

Results

Weed occurrence

Six weed species were recorded in the control plot (SF) with no herbicide and rice bran application under shallow flooding (Table 1). Four weed species such as *Monochoria vaginalis, Echinochloa crus-galli, Ludvigia prostrate, and Cyperus amuricus* were dominant as found in the common paddy field of Korea. Herbicide treatment (SF+HB) controlled most of the weeds effectively except *Ludvigia prostrata* (weed suppression efficacy of 57.1%). Deep flooding (DF) and rice bran application under deep flooding (DF+LRB and DF+HRD) suppressed *Aneilma keisak and Bidens tripartita* completely, while showing differential suppression effect depending on the species of the four dominant weeds. Deep flooding without rice bran application (DF) decreased the occurrence of *Echinochloa crus-galli* and *Cyperus amuricus* significantly, showing suppression efficacy of 84.0 and 77.4%, respectively, while it did not suppress the occurrence of *Monochoria vaginalis* and *Ludwigia prostrate* (Tables 1 and 2). On the contrary to the deep flooding treatment, rice bran application showed significant suppression effect on *Monochoria vaginalis* and *Ludwigia prostrate* but no suppression effect on *Echinochloa crus-galli* and *Cyperus amuricus* (Table 2).

Deep flooding and rice bran application showed complementary suppression effect on the four dominant weed species. Thus, the combined treatment of deep flooding and rice bran application showed effective suppression in more weed species than the treatment of any one of them. Although it was not higher than herbicide application, rice bran application under deep flooding showed satisfactory suppression efficacy for the dominant weed species except *Monochoria vaginalis*. *Monochoria vaginalis* was significantly suppressed by rice bran application under deep flooding, but not to a satisfactory degree, and showed a suppression efficacy of only about 30%.

Table 1. Weed occurrence as affected by rice bran application and water depth in rice field at 40 days after transplanting.

Species	SF[a] (no./500cm²)	SF+HB (no./500cm²)	DF (no./500cm²)	DF+LRB (no./500cm²)	DF+HRB (no./500cm²)
Monochoria vaginalis	15.7 a (0)[b]	2.0 c (87.2)	18 ac (-14.9)	11 b (29.8)	10.7 b (31.9)
Echinochloa crus-galli	8.3 a (0)	0.5 b (94)	1.3 b (84.0)	5.0 b (40.0)	2.3 b (72.0)
Ludwigia prostrata	16.3 a (0)	7.0 bc (57.1)	14.0 a (14.3)	4.3 c (73.5)	7.0 bc (57.1)
Cyperus amuricus	16.0 a (0)	1.7 b (89.6)	3.7 b (77.1)	5.0 b (68.6)	4.0 b (75.0)
Aneilma keisak	1.0 a (0)	0 b (100)	0 b (100)	0 b (100)	0 b (100)
Bidens tripartita	1.3 a (0)	0 b (100)	0 b (100)	0 b (100)	0 b (100)

[a] SF, shallow flooding; DF, deep flooding; LRB, applying low dose of rice bran (1,000 kg ha⁻¹); HRB, applying high dose of rice bran (2,000 kg ha⁻¹); HB, applying herbicide.
[b] Numbers in parentheses are the suppression efficacy (%) compared with control (SF treatment).
[c] Values with the same letters in a row are not significantly different at the 0.05 probability level.

Table 2. Comparison of weed occurrence according to flooding depth and rice bran application under deep flooding in four dominant weed species.

	Monochoria vaginalis	*Echinochloa crus-galli*	*Monochoria vaginalis*	*Monochoria vaginalis*
	(a) Effect of flood depth (no./500cm²)			
SF[a]	15. 7a[b]	8.3a	16.3a	16.0a
DF	18.0a	1.3b	14.0a	3.7b
	(b) Effect of rice bran (no./500cm²) under deep flooding			
DF	18.0a	1.3a	14.0a	3.7a
DF+LRB	11.0b	5.0a	4.3b	5.0a
DF+HRB	10.7b	2.3a	7.0b	4.0a

[a] The abbreviations for treatment codes are the same as described in the footnote of Table 1.
[b] Values with the same letters in a column are not significantly different at the 0.05 probability level.

Flood water and soil environment

Dissolved oxygen of flood water

Dissolved oxygen (DO) dropped to the lowest level on the next day of deep flooding and rice bran application at 7 DAT and thereafter increased steadily until around 20 DAT (Fig. 1). DO level was lowered significantly by deep flooding (DF), compared to shallow flooding (SF and SF+HB). DO of DF treatment (3.1 mg L^{-1}) was nearly half of the SF (5.7 mg L^{-1}) and SF+HB (6.8 mg L^{-1}) treatment at 8 DAT and the difference was narrowed rapidly thereafter until 19 DAT. Because deep flooding deterred O_2 diffusion and rice bran decomposition consumed a lot of O_2, rice bran application under deep flooding (DF+LRB and DF+HRB) lowered DO level below 2mg/L and maintained a much lower DO level than the other treatments until 19 DAT. DO level was lower in the higher dose of rice bran (DF+HRB) than in the lower dose (DF+LRB).

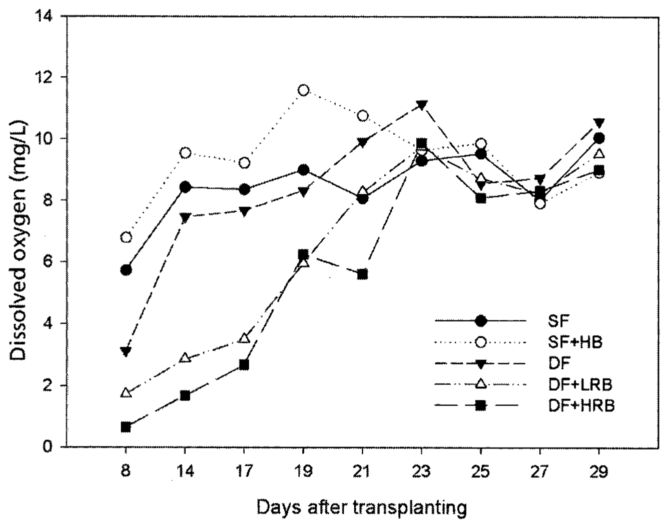

Fig. 1. Temporal changes in dissolved oxygen concentration in floodwater of paddy field as affected by rice bran application and irrigation water depth. The abbreviations for treatment codes are the same as described in the footnote of Table 1.

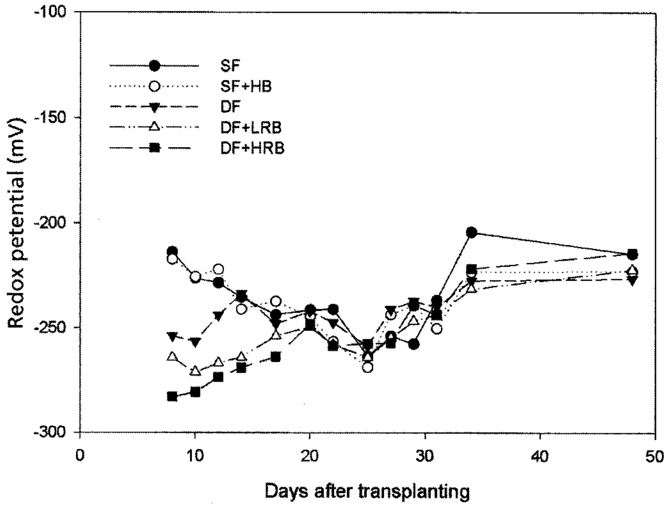

Fig. 2. Temporal changes in redox potential at 2 cm depth of paddy soil as affected by rice bran application and water depth. The abbreviations for treatment codes are the same as described in the footnote of Table 1.

Soil redox potential

As shown in Fig. 2, the redox potential (Eh) of soil (2 cm below soil surface) was lowered drastically one day after deep flooding at 7 DAT and subsequently increased, reaching the same level with shallow flooding (SF and SF+HB) at 14 DAT. Compared to deep flooding (DF), soil Eh dropped to much lower level in rice bran application under deep flooding (DF+LRB and DF+HRB).

Soil mineral nitrogen

Soil mineral nitrogen (NO_3-N and NH_4-N) concentration in the top soil increased rapidly since fermented compost was applied three days before transplanting, reached the maximum level at 30 DAT, and then dropped to the minimum level before the additional dressing of compost at 55 DAT (Fig. 3). There

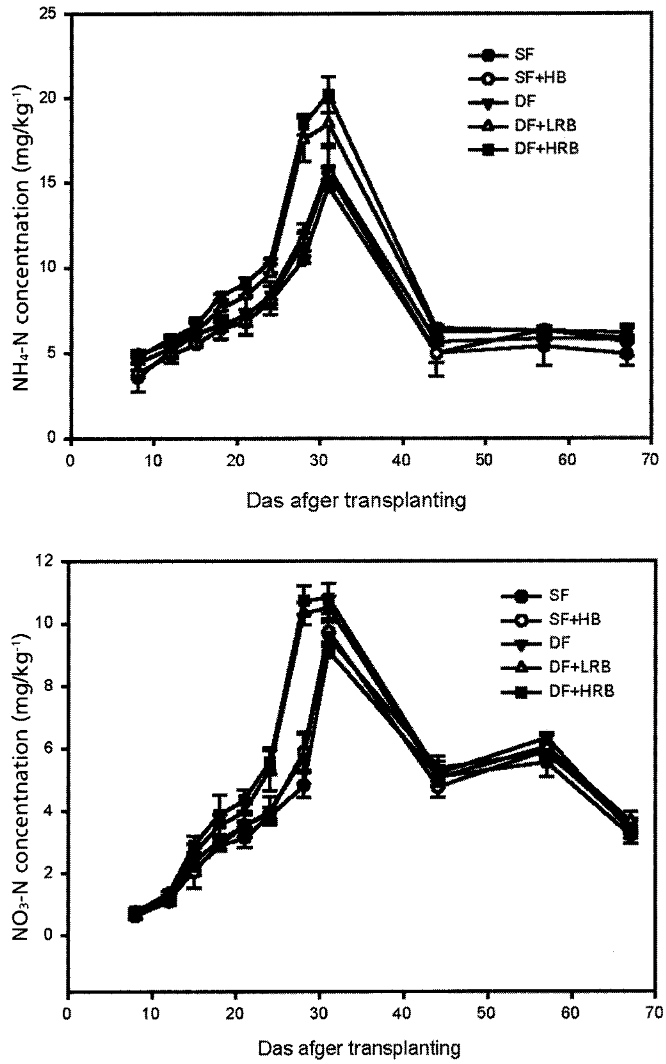

Fig. 3. Temporal changes in NH_4-N and NO_3-N concentration of surface soil (15 cm) of field as affected by rice bran application and water depth. The abbreviations for treatment codes are the same as described in the footnote of Table 1.

was no difference in soil mineral nitrogen concentration between shallow flooding (SH and SH+HB) and deep flooding (DF). However, rice bran application (DF+LRB and DF+HRB) increased it significantly compared to the treatments without rice bran application.

Rice growth and yield

Tiller production

As in Fig. 4, tiller number was the highest in shallow flooding with herbicide application (SF+HB). Deep flooding (DF) significantly decreased tiller number compared to SH+HB. However, the tiller number in deep flooding with rice bran application (DF+LRB and DF+HRB) was much higher than in deep flooding without rice bran application (DF) and was almost to the same as that in SF+HB especially in the later growth stage. The tiller number in shallow flooding without weeding treatment (SF) was the lowest.

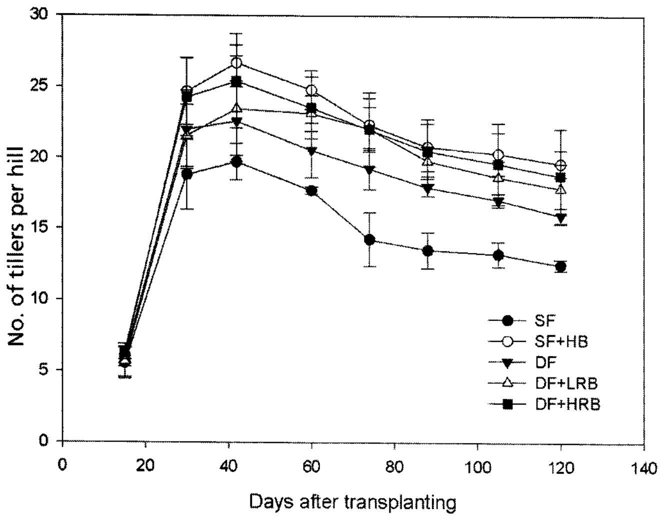

Fig. 4. Temporal changes in the number of tillers per hill as affected by rice bran application and flood water depth. The abbreviations for treatment codes are the same as described in the footnote of Table 1.

Plant nitrogen concentration and content at harvest

Plant nitrogen concentration and content at harvest was affected by both flooding depth and rice bran application (Table 3). Nitrogen concentration and content in straw was lower in deep flooding (DF) than in shallow flooding (SF+HB) and vice versa in grain (Table 3). Shoot nitrogen content was slightly lower in DF than in DF+HB. Rice bran application under deep flooding (DF+LRB and DF+HRB) significantly increased the nitrogen concentration and content of straw, grain, and shoot compared to the treatments without rice bran application. Nitrogen content in straw and grain was the lowest in shallow flooding without weeding (SH).

Grain yield and yield components

Flooding depth and rice bran application exerted a significant influence on grain yield and yield components as shown in Table 4. In general, deep flooding (DF) decreased the total number of spikelets compared to shallow flooding with herbicide application (SH+HB) as deep flooding showed a more substantial decrease in the panicle number than the increase in spikelet number per panicle. Due to the lower total spikelet number and ripened grain ratio, the grain yield of DF was significantly lower than that of SH+HB. Rice bran application under deep flooding (DF+LRB and HRB) increased the panicle number, spikelet number per panicle, and thus grain yield significantly, compared with the deep flooding without rice bran application (DF). Furthermore, rice bran application with higher dose under deep flooding (DF+HRB) produced significantly higher grain yield than shallow flooding with herbicide application (SF+HB) due to the significant increase in total number of spikelets. The increased total number of spikelets in DF+HRB resulted from the significant increase in both panicle number and spikelet number per panicle. Grain yield of shallow flooding without weeding (SF) was the lowest mainly due to the substantial reduction in panicle number.

Discussion

Effect of rice bran application under deep flooding on weed occurrence

In the experimental field, six weed species occurred in the plot subjected to shallow flooding and no herbicide application (Table 1). Among these, four species, *Echinochloa crus-galli, Cyperus amuricus, Monochoria vaginalis*, and *Ludwigia prostrate*, were dominant as reported by Kim et al. (2001) in the same province. It is well known that flooding hinders weed germination and suppresses the weed population of already emerged weeds, depending on the nature of weed flora. Among the four dominant weed species, deep flooding (8-10 cm) effectively suppressed the two weed species: *Echinochloa crus-galli* and *Cyperus amuricus*, but had no suppression effect on the other two species: *Monochoria vaginalis* and *Ludwigia prostrata*) (Tables 1 and 2). These results are in good agreement with other reports that continuous submergence considerably suppressed *Echinochloa crus-galli* (Catizone 1983; Mukhopadhyay 1983; Smith and Fox 1973), flooding over 10 cm depth at the first-leaf stage almost completely suppressed the growth of *Echinochloa crus-galli and praticola* (Kwon et al. 1996), and *Monochoria vaginalis* was not significantly affected by submergence (Pons 1982). On the contrary to deep flooding, rice bran application suppressed *Monochoria vaginalis* and *Ludwigia prostrate* to a substantial degree, but not the other two species (Table 2). Similarly, Kim et al. (2001) reported that rice bran application had little suppression effect on *Echinochloa crus-galli*, but *suppressed Monochoria vaginalis, Scirpus juncoides*, and *Cyperus serotinus* to a substantial degree. Deep flooding in combination with rice bran application significantly suppressed the occurrence of all six weeds including the four dominant weeds (Table 1). Weed suppression efficacy of *Echinochloa crus-galli, Cyperus amuricusb, Ludwigia prostrate*, and *Monochoria vaginalis* were 72, 73.5, 75, and 31.9%, respectively. These results suggested that deep flooding and rice bran application had differential suppression effects depending on weed species, and thus the combined treatment of deep flooding and rice bran application could suppress weed complementarily, resulting in better weed control.

When soils are flooded, the ratio of carbon dioxide to oxygen typically increases and can have detrimental effects on seed germination and seedling emergence (Forcella et al. 2000). One day after deep flooding, dissolved oxygen levels in flood water just over the soil surface dropped to almost half compared to shallow flooding by deterred diffusion of oxygen and also redox potential (Eh) of top soil was reduced to much lower levels. Rice bran application under deep irrigation further lowered DO and Eh levels and maintained low DO and Eh longer compared to deep flooding without rice bran application (Fig. 1 and 2). As mentioned above, *Echinochloa crus-galli* and *Cyperus amuricus* was significantly suppressed by a single treatment of deep flooding and there was no additional suppression effect on them due to rice bran application under deep flooding. And *Monochoria vaginalis* and *Ludwigia prostrate* were substantially suppressed by rice bran application under deep flooding but not by single deep flooding treatments. These results suggested that rice bran

Table 3. Effect of flooding depth and rice bran application on plant nitrogen concentration and content at harvest.

Treatment	Nitrogen concentration (g kg⁻¹)		Nitrogen content (kg ha⁻¹)		
	Straw	Grain	Straw	Grain	Total
SF[a]	7.12a[b]	10.79bc	29.7c	40.4d	70.0d
SF+HB	5.32b	11.04b	29.9c	61.0b	90.9bc
DF	6.37ab	10.08c	35.7bc	51.4c	87.1cd
DF+LRB	6.49a	11.01b	43.3b	63.9ab	107.1b
DF+HRB	7.36a	12.33a	55.9a	71.9a	127.8a

[a] The abbreviations for treatment codes are the same as described in the footnote of Table 1.
[b] Values with the same letters in a column are not significantly different at the 0.05 probability level.

has an inherent effect on weed suppression and that oxygen requirements for germination and seedling growth are different according to weed species. Kuk et al. (2001) reported that the aqueous extracts of rice bran significantly inhibited the germination and early growth of *Eclipta prostrata* even at a low concentration of the extract but *Echinochloa crus-galli* to a much less extent (Kuk et al. 2001). It was suggested that the inhibitory effect of rice bran on weed suppression would be ascribed to ABA (Kuk et al. 2001) but it still remains to be proven.

Effect of rice bran application under deep flooding on grain yield

Deep flooding decreased the total number of spikelets compared to shallow flooding with herbicide application as deep flooding resulted to a more substantial decrease in the panicle number than the increase in spikelet number per panicle (Table 4) as reported by Myung (1997) and Zeng et al. (2003). Due to the lower total spikelet number and ripened grain ratio, grain yield of deep flooding was significantly lower than that of shallow flooding with herbicide application (Table 4). However, grain yield under deep flooding was higher than under shallow flooding without any weeding treatment in which many weeds occurred. Weed occurrence had a highly negative correlation with grain yield and some yield components such as panicle number and total spikelet number (Table 5).

Rice bran application under deep flooding significantly increased both spikelet number per panicle and panicle number, leading to substantial increase in total spikelet number per unit area and grain yield compared to deep flooding with no rice bran

Table 4. Effect of flooding depth and rice bran application on grain yield and yield components.

Treatment	Panicles (No. m⁻²)	Spikelet Number per Panicle	Total Spikelets Number (x1000 m⁻²)	Ripened Grain Ratio (%)	1000 Grain Weight (g)	Grain Yield (kg ha⁻¹)
SF[a]	277e[b]	66.32c	18.39c	87.76ab	23.66a	3785.3d
SF+HB	451a	60.33bc	27.02ab	90.67a	24.09a	5902.6ab
DF	355d	69.52ab	24.84b	87.79ab	24.13a	5207.8c
DF+LRB	402c	74.68a	30.16a	79.60b	23.82a	5588.1bc
DF+HRB	422b	76.53a	31.80a	79.63b	24.14a	6083.3a

[a] The abbreviations for treatment codes are the same as described in the footnote of Table 1.
[b] Values with the same letters in a column are not significantly different at the 0.05 probability level.

Table 5. Correlations between weed numbers recorded at 40 days after transplanting and yield components.

Item	Panicle Number	Spikelet Number per Panicle	Total Spikelet Number	Ripened Grain Percentage	1000 Grain Weight	Grain Yield
Weed number	-0.9356**	0.0524^{NS}	-0.6838**	0.0480^{NS}	-0.2731^{NS}	-0.8580**

*,** , and NS: significant at the probability levels of 0.05 and 0.01 ant not significant, respectively

Table 6. Correlations between inorganic nitrogen concentrations in the top soil of 15 cm depth at 30 days after tillering stage and yield components.

Item	Panicle number	Spikelet Number per panicle	Total spikelet number	Ripened Grain percentage	1000 grain weight	Grain yield
NH_4-N concentration	0.4674^{NS}	0.6520**	0.7766**	-0.7117**	0.1789^{NS}	0.6210*
NO_3-N concentration	0.6135*	0.5181*	0.7736**	-0.5804*	0.2748**	0.6956**

*,** , and NS: significant at the probability levels of 0.05 and 0.01 ant not significant, respectively

application (Table 4). Nitrogen status before the booting stage of rice is important to the formation of rice yield components such as panicle number, spikelet number, and thus grain yield (Cui and Lee 2002). Rice bran application at 7 DAT for weed suppression significantly increased mineral nitrogen concentration in the top soil during tillering stage (Fig. 3), providing much more available nitrogen for rice growth. The added nitrogen by rice bran application can contribute to the increase in mineral nitrogen concentration in soil, but the nitrogen quantity from rice bran alone cannot cause such a big difference. Lee et al. (2001) reported that rice bran could increase the bacterial population in paddy soil and the increased bacterial population accelerated the decomposition of compost. The higher inorganic nitrogen content in soil at early growth stage of rice might be partly due to more nitrogen application from rice bran, but is mostly due to the accelerated decomposition of the compost applied. As shown in Table 6, mineral nitrogen concentration at tillering stage (40 DAT) had a significant positive correlation with the panicle number, spikelet number per panicle, total number of spikelets, and thus grain yield. This suggested that the higher mineral nitrogen concentration in top soil at early growth stage of rice, which was induced by rice bran applied at 7 DAT for weed suppression, brought about higher grain yield of rice.

In conclusion, rice bran application in combination with deep flooding not only effectively suppressed major paddy weeds without herbicide use but also increased grain yield by increasing soil mineral nitrogen concentration. Therefore, this practice would be incorporated as an integral part of herbicide free organic rice farming.

Acknowledgement

This work was funded by the Korea Meteorological Administration Research and Development Program under Grant CATER 2006-4301.

References

Avery D. 1999. Risk, health, and environment, In: Morris J., Bate R. (Eds), Fearing Food, Butterworth-Heinemann, Oxford, UK, pp: 3-18

Bhagat RM, Bhuiyan SI, Moody K. 1996. Water, tillage, and weed interactions in lowland tropical rice. A review, Agric. water manage. 31: 165-184

Bhan VM. 1983. Effect of hydrology, soil moisture regime and fertility management on weed population and their control in rice, In: Proceedings of the conference on weed control in rice at International Rice Research Institute, LOS Banos, Philippines Aug 31-Sep. pp: 47-56

Catizone P. 1983. Farmer's weed control technology in rice in Southern Europe. In: Proceedings of the conference on weed control in rice at international Rice Research Institute, LOS Banos, Philippines Aug 31-Sep. pp: 183-191

Cho DH, Jung JB, Lee GW. 1999. Investigation of management of organic farming: The circumstance of rice farmer conducting environment-friendly rice farming in Jeonnam, Jeonnam Agricultural Res. and Ext. Services. pp: 228-239

Cui RX, Lee BW. 2002. Spikelet number estimation model using nitrogen nutrition status and biomass at panicle initiation and heeding stage of rice, Kor. J. Crop Sci. 47: 290-394

Drinkwater LE, Wagoner P, Sarrantonio M. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses, Nature. 396: 262-265

Forcella F, Arnold RLB, Sanchez R, Ghersa CM. 2000. Modeling seedling emergence, Field Crops Res. 67: 123-139

Greene C. 2000. US organic agriculture gaining ground, Agricultural Outlook. 270: 9-14

Ishii R. 1995. Photosynthesis, respiration and grain yield, in: Science of The Rice Plant, Volume two: Physiology (Eds: Matsuo T., Kumazawa K., Ishii R., Ishiharea K., Hirata H.). Food and Agric. Policy Res. Center, Tokyo, Japan, pp: 691-703

Joshi RC, Martin EC, Wada T, Sebastian LS. 2005. Role of golden apple snail in organic rice cultivation and weed management, in: Proceedings of the Conference on "Researching Sustainable Systems," 15th IFOAM World Organic Congress, 21-23rd Sep 2005, Adelaide, Australia, pp: 112-115

Juliano BO, Bechtel DB. 1985. The rice grain and its gross composition, In: Juliano B.O. (Ed), Rice: Chemistry and Technology, The American Association of Cereal Chemists, St. Paul, MN. pp: 17-58

Kim JG, Lee SB, Lee KB, Lee DB, Kim JD. 2001. Effect of applied amount and time of rice bran on the rice growth condition, Kor. J. Environ. Agric. 20: 15-19

Kirchmann H, Thorvaldsson G. 2000. Challenging targets for future agriculture, Eur. J. Agron. 12: 145-161

Kuk YI, Shin JS, Kwon OD, Guh JO. 2001. Effect of aqueous extracts of rice bran on inhibition of germination and early growth of weeds, Kor. J. Environ. Agric. 20: 108-111

Kwon YW, Lee BW, Kim DS. 1996. Agroecological aspects of occurrence and control of barnyardgrass in the rice fields, in: Proceeding of northeast Asian area weed science symposium of China, Korea and China. pp: 64-70

Lee SB, Yoo CH, Kim JG, Kim JD, Lee DB, Lee KB, Han SS. 2001. Rice bran and charcoal meal application on rice growth and bacterial population in paddy soil, Kor. J. Soil Sci. Fert. 34: 178-184

MAF (Ministry of Agriculture and Forestry, The Republic of Korea). 2005. Environment-friendly agriculture, in: www.maf.go.kr

Matson PA, Parton WJ, Power AG, Swift MJ. 1997. Agricultural intensification and ecosystem properties, Science. 277: 504-509

Moody K, Datta De SK, Bhan VM, Manna GB. 1986. Weed control in rainfed lowland rice, in: Progress in Rainfed Lowland Rice, IRRI, Philippines, pp: 359-370

Mukhopadhyay SK. 1983. Weed control technology in rainfed wetland rice, in: Proceeding of the Conference on Weed Control in Rice, IRRI, Philippines, pp: 109-118

Myung EJ. 1997. Suppressing of tillering in the deep-irrigated rice plants and its mechanism, PhD Dissertation, Seoul National University, Seoul, Korea

Pons TL. 1982. Factors affecting weed seed germination and seedling growth in lowland rice in Indonesia, Weed Res. 22: 155-161

Raju RA, Reddy MN. 1987. Influence of water regimes on the weed flora of transplanted lowland rice ecosystem, Andhra Agric. J. 34: 459-461

Reganold JP, Palmer AS, Lockhart JC, Macgregor AN. 1993. Soil quality and financial performance of biodynamic and conventional farms in New Zealand, Science. 260: 344-349

Reganold JP, Glover JD, Andrews PK, Hinman HR. 2001. Sustainability of three apple production systems, Nature. 410: 926-930

Sahid IB, Hossan MS. 1995. The effect of flooding and sowing depth on the survival and growth of five rice weed species, Plant Protection Q. 10: 139-142

Smith RJ, Fox WT. 1973. Soil water and the growth of rice and weeds, Weed Sci. 21: 59-63

Tillman D. 1999. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices, Proc. Nat'l Acad. Sci. USA. 96: 5995-6000

Trewavas A. 1999. Much food, many problems, Nature. 402: 231-232

Yamada N. 1959. Physiological basis of resistance of rice plant against overhead flooding, Bull. Nat'l. Agric. Sci. Ser. D. 8: 110

Zeng LH, Lesch SM, Grieve CM. 2003. Rice growth and yield respond to changes in water depth and salinity stress. Agric. Water Manag. 59: 67-75