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Full Length Research Paper

Effects of green manure crops and mulching technology on reduction in herbicide and fertilizer use during rice cultivation in Korea

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Green manure crops are primarily used in environmentally friendly agricultural practices to reduce the application of chemical fertilizer and herbicide. In this study, a two-year field experiment was conducted to evaluate the effects of paper and plastic mulching with hairy vetch alone or in combination with barley on weed control and rice yield. In addition, treatment effects on soil redox potential (Eh) and the concentration of ammonium (NH_4^+) in rice paddy were investigated. The results showed that plastic film (10 or 20 μm) and paper mulching with hairy vetch alone had no significant effects on weed density and rice yield when compared with conventional practice (herbicide and fertilizer application) during the first year. However, during the second year, plastic film (20 μm) with partial tillage of hairy vetch alone increased rice yield and decreased weed occurence; but barley and hairy vetch mixture showed opposite trends. Plastic film mulching led to a decrease in soil redox potential, mainly due to the decomposition of soil organic matter. In addition, plastic film mulching increased NH_4^+-N contents in rice paddy soil. These results suggest that the combination of plastic film with hairy vetch and barley mixture can be used in rice fields to reduce the use of chemical fertilizer and herbicide.

Key words: Green manure, hairy vetch, mulching, rice, weed control.

INTRODUCTION

Paddy rice (*Oryza sativa* L.) is one of the main crops cultivated in Korea and therefore, Korean rice growers have used a large amount of chemical fertilizer and herbicide to increase rice field's productivity (Rüegg et al., 2007). Unfortunately, the excessive use of agrochemicals creates soil and water pollution, resulting in an adverse effect on surrounding environment and human health (Rice et al., 2001). The incorporation of plant residues into the soil is of the importance to reduce the soil application of agrochemicals. This technology is an important practical issue used when returning straw to the soil because straw contains plant nutrients. Additionally, this technology is safe for human health and environmentally friendly. The principles and key points of environmentally friendly agriculture (EFA) should result in low-input of agrochemicals to improve soil ecosystems, leading to production of a safe food product. In Korea, some EFA techniques have been implemented nationwide for rice production to reduce the use of chemical fertilizer and herbicide inputs (Jeon et al., 2006).

Paper and plastic mulching with plant residues has become an alternative technique to reduce agrochemicals for rice cultivation in Korea. Recently, paper mulches have received an increasing attention because they are biodegradable materials (Jeon et al., 2005; Lee et al., 2005). However, paper mulches have been plagued by problems such as high cost and weed occurrence as a result of the paper tearing (Jeon et al., 2007). There are different mulching technologies in Japan, which uses recycled paper for weed control (Umezaki and Tsuno, 1998) and in China where film mulching is used to save water (Liu et al.

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Abbreviations: CRV, Controlled release fertilizer; **DAT,** days after transplantation; **Eh,** redox potential; **PTHV,** partial tillage hairy vetch alone; **EFA,** environmentally friendly agriculture.

2003; Fan et al., 2005). Recently, colored and reflective paper mulches have been developed to meet the requirements of individual crops and locations. It is well known that plastic mulch film increases the yields of many crops by inhibiting weed growth and increasing soil temperature and moisture as well as reducing pest infestations. The use of plastic mulch has also become a standard practice for many farmers to control weeds; thus, it can contribute significantly to the economic viability worldwide (Singh et al., 2007).

The addition of organic fertilizer or compost can also manage the application of chemical fertilizer. Based on nutrient cycling, green manure crops are suitable and very attractive to use by farmers in EFA (Liebman and Davis, 2000). Previous studies have revealed that the use of green manure crops could lead to increase soil organic matter and nitrogen availability. Green manure crops include legume residues as well as grass crops such as rye and barley. The main advantages of such manures are: (1) the improvement of the physico-chemical soil properties (Sarrantonio and Gallandt, 2003; Jeon et al., 2008); (2) the management of weeds (Hatcher and Melander, 2003); (3) the protection from nematodes (DuPont et al., 2009). In Korea, a large amount of hairy vetch fresh weight is produced (20 ton ha^{-1}) and this crop generally contains an average of 110 kg N ha^{-1} (Jeon et al., 2008). Therefore, hairy vetch (*Vicia villosa*) and Chinese milk vetch (*Astrogulus sinicus*) mulch have primarily been studied for rice cultivation in Korea (Jeon et al., 2010; Kim et al., 2009; Lee, 2010). Nevertheless, information regarding the beneficial effects of hairy vetch mulching on the productivity and sustainability of rice and weed control is meager. Therefore, the objectives of this study were to investigate the beneficial effects of hairy vetch and mulching as an alternative technique for chemical fertilizer and herbicide on chemical soil properties, rice yield and weed control.

MATERIALS AND METHODS

Description of the experimental site

A field experiment was conducted in a paddy soil (Fine loamy, mixed, nonacid and mesic family of Aeric Fluventic Haplaquepts) at the National Institute of Crop Science (NICS) in Suwon, Korea, during two years, 2005/2006 and 2006/2007. The annual precipitation in the site depends largely on precipitation during the summer rainy season, which is strongly controlled by the East Asian summer monsoon system. Climatologically, heavy precipitation over Korea primarily occurs from a quasi-stationary polar front for a period of 30 to 40 days from late June through July, while precipitation in this period accounts for more than 40% of the annual precipitation (Lee et al., 1998). The soil used in this study is a silt loam (clay 15.3%, silt 51.1% and sandy 33.6%) with a bulk density of 1.43 g cm^{-3}. The top 15 cm prior to sowing green manure contained 22.1 g kg^{-1} organic matter and pH 5.4 (soil water ratio 1:5).

Green manure preparation

A green manure crop rice rotation system was implemented from October 2005 to May 2006 in a field that had previously been cropped with a rice monoculture system. After the harvest of rice, the soil was mixed with a tractor machine (LG-L65 model, Korea) and hairy vetch seed (*V. villosa*) was then applied to the top surface of the soil (15 cm) at a rate of 90 kg ha^{-1} on October 7, 2005. After harvest of the hairy vetch, the above ground portion of the plant was measured and then dried in an oven at 70°C, until a constant weight was obtained to measure the dry weight. Moreover, the total carbon (C) and total nitrogen (N) were measured using a CNS analyzer (Leco, USA). Hairy vetch green manure was composed of 3120 kg dry matter ha^{-1} containing 109.2 kg N ha^{-1} and a C/N ratio of 15.3. The harvested hairy vetch was used to cover the soil and was also incorporated into the soil during the mulching treatments in the first season (May 20, 2006). During this season, the green manure crop (Hairy vetch) was applied using the drill seeding system.

Conversely, the seeding of hairy vetch alone or in combination with barley was applied during the second season (2006/2007) using a partial tillage system instead of drill seeding. The seeder machine used for partial tillage was developed by the Department of Agricultural Engineering, Rural Development Administration and Jang Automation Co. (Korea). In addition, a partial tillage seeder was attached to the tractor. This seeder consisted of eight horizontal rows of a rotary system with a drainage channel in the center of the seeder (Jeon et al., 2008). The rice seedling transplanting, and paper and plastic mulching technology are shown in Figure 1. The tillage seeding of green manure crops during the second season was comprised of hairy vetch alone or in combination with barley. The hairy vetch alone and hairy vetch and barley mixed treatments were seeded on October 9, 2006. The application rate of the hairy vetch seed was 90 kg ha^{-1}. Moreover, the application rates of hairy vetch and barley seeds were 60 kg ha^{-1} and 70 kg ha^{-1}, respectively. The hairy vetch cultivar, H-1, was imported from China and barley cultivar, Yeoungyang, was supplied by the National Institute of Crop Science. The biomass of green manure crops and total C and total N were measured using the same methods described for the first season. The biomass, N production and C/N ratio of treatments for rice cultivation were presented by our previous work (Jeon et al., 2008). The incorporation of hairy vetch alone or in combination with barley was conducted on May 16, 2007.

Experimental design and treatments

During the first season, a field experiment (2005/2006) was conducted to evaluate the effects of paper color and plastic film mulching technology using hairy vetch as green manure for rice cultivation on weed density and rice yield. Specifically, the following six treatments were applied: conventional practice (NPK + herbicide), white paper mulching (10 µm), black paper mulching (10 µm), plastic film mulching (10 µm), plastic film mulching (20 µm) and control. Paper mulch (1.9 m width and 198 m length) was made from compound papers that were coated with biodegradable plastics by the National Institute of Crop Science and SK Chemical in Korea. Plastic films used in this study were obtained from Kyung Seong Vinyl, Korea. Additionally, plastic mulch was made from polyethylene film and had the strength and stretch to ensure a tight fit over raised beds. Finally, certain plastic mulches also acted as a barrier to keep methyl bromide, a powerful fumigant and ozone depleter in the soil.

A second season field experiment (2006/2007) was also conducted to evaluate the effects of plastic film mulching using hairy vetch alone or in combination with barley applied as green manure on the soil redox potential and ammonium nitrogen in the soil.

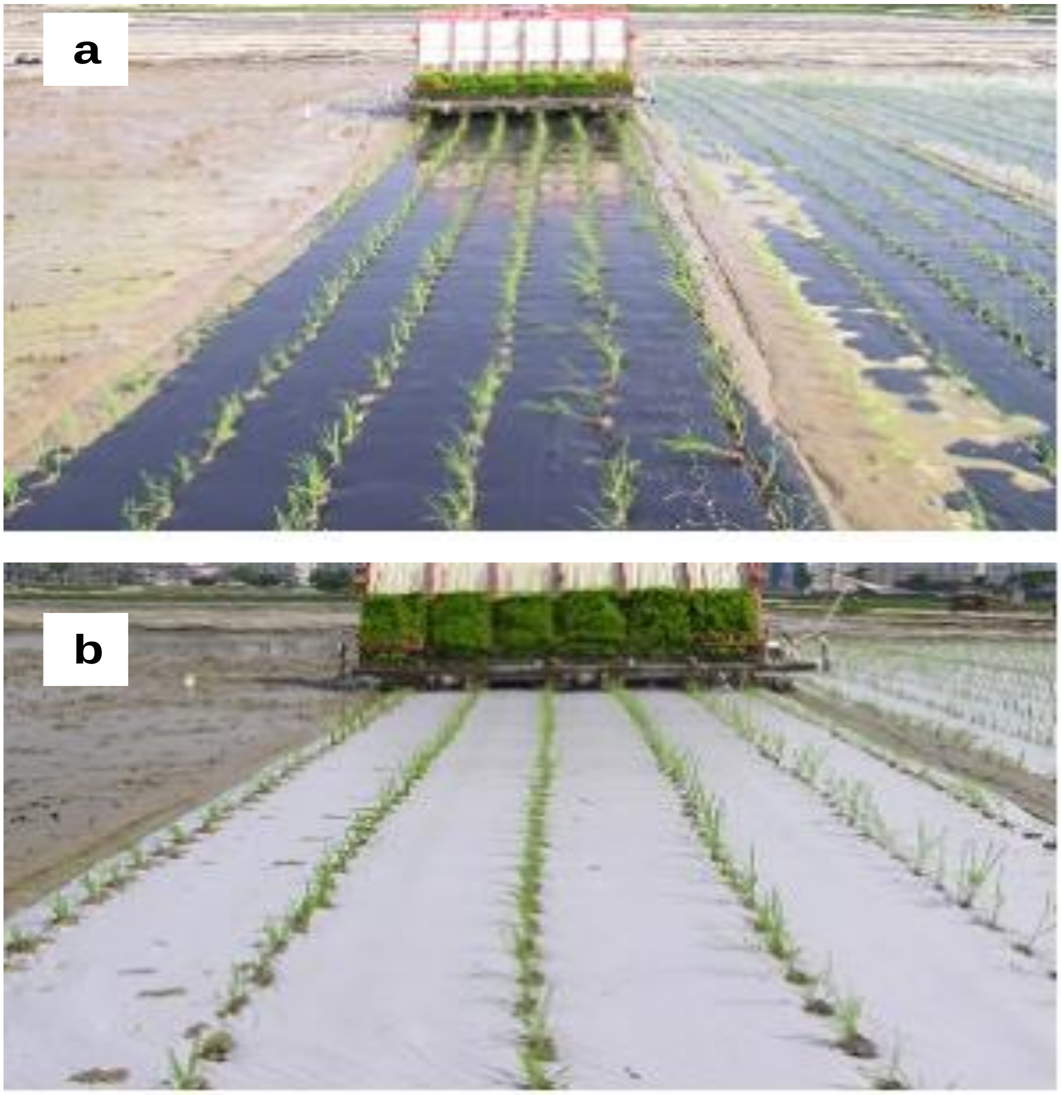

Figure 1. Rice seedling transplanting in the black plastic film (a) and paper (b) mulching treatment.

The effects of the treatments on weed control and rice yield were also investigated in this season. Specifically, the following five treatments were applied: Conventional practice (NPK + herbicide), plastic film mulching (20 µm) using two technologies; partial tillage using hairy vetch alone (PTHV) or in combination with barley (PTM) and control (partial tillage using hairy vetch alone or in combination with barley without mulching).

The plastic films were removed from the field at 41 days after transplanting in both the first and second seasons. The experiments were conducted using a randomized complete block design with three replications for each block (200 m^2). For rice mulching, a mulching (RP660GU-PV, Kukje, Korea) transplanter machine developed by the Department of Agricultural Engineering, Rural Development Administration and Kukje Machinery in Korea was used. Moreover, a transplanter machine was modified to have six rows and a mulching system that included a cutting device. Chemical fertilizer was applied as latex coated urea ($N:P_2O_5:K_2O$ equal 21:7:9) at a rate of 88 kg ha^{-1}. Because latex coated urea is a controlled-release fertilizer, the amount of nitrogen applied was 80% (88 kg ha^{-1}) when compared with the nitrogen amount (110 kg ha^{-1}) of other conventional chemical fertilizer. In addition, chemical fertilizer was broadcast into the surface soil (15 cm) using a plough prior to mulching and transplanting of rice. Finally, herbicide (pyrazosulfuron-ethyl; Sungbo Chemical Co. LTD., Korea) was applied at a rate of 30 kg ha^{-1} at seven days after transplanting. Rice (*O. sativa* L. cultivar Pungmibyeo) seedlings that were 25 days old were transplanted using the transplanting machine at 30 x 14 cm spacing on June 2 during the first season and on June 8 during the second season.

Rice and weed measurements and soil analyses

The rice yield and yield components were investigated during the first season of the experiment (2005/2006). Additionally, similar measurements were conducted on rice during the second season (2006/2007). At the rice ripening stage, plants were randomly collected from each plot to determine the yield components (Panicle number (no m^{-2}), number of spikelets (no m^{-2}), percentage of ripened grain (%), 1000-grain weight (g) and calculated milled rice yield (kg ha^{-1})). Soil samples were only collected during the second season (2006/2007) to investigate the effects of plastic film mulching (20 µm) on some soil properties. Specifically, redox potential (Eh) was measured directly using a potential meter (Orion 678BN, USA) at a depth of 5 cm using the Pt electrode for 20 ± 25 min equilibrium with the soil. For calibration of the potential meter, Zobell's solution was used to calibrate the ORP pt/Ag/AgCl electrode and 198 mV was added to the observed readings to standardize the Eh reading to the standard hydrogen electrode (Tanji et al., 2003). Moreover, the ammonium nitrogen content in soil was determined using FIAstar-5000 (FOSS Sweden) after soil extraction with 2 M potassium chloride solution (RDA, 1988).

To evaluate the effects of paper and plastic mulching technology on weed control, weed density and weed dry weight data were determined at the maximum tillering stage of rice (48 DAT). Specifically, the weed density was estimated with a quadrate (0.3 x 1.0 m) placed randomly three times at two spots in each plot (midpoint and edge of mulching). Next, the weeds were cut at ground level, washed and then dried at 70°C for 2 days, after which they were weighed. The percentage of weed suppression was also estimated based on comparison to a control.

Statistical analyses

Differences among treatments were estimated by one-way analysis of variance (ANOVA) using the SAS program (SAS institute, ver. 9.2, 2004) with Tukey's LSD. Differences were considered significant at $p < 0.05$.

RESULTS AND DISCUSSION

Weed control

Mulch can play an important role in the control of weeds in cropping systems. During the first season of this study, the density and dry weight of weeds were estimated at 41 days after transplantation of rice seedlings and incorporation of hairy vetch alone (Table 1). The weed parameters were estimated at the maximum tillering stage of rice and at the time at which the canopies formed. The results showed that, the no mulch treatment (control) had a higher total weed density and dry weight of weeds than the treatments of mulch or conventional practice (Table 1). The weeds, which were associated with seeded rice during the first season, include *Monochoria vaginalis*, *Cyperus difformis*, *Aneilema keisak*, *Ludwigia prostrate*, *Lindernia procumbens*, *Eleocharis kuroguwai* and *Rotala indica*. In addition, the weeds density was consistently lower in all mulch treatments, with a reduction of more than 96%. In the control and white paper mulch treatments, *M. vaginalis was* the dominant weed (Table 1). Similarly, the weeds dry weight was lower in the mulch treatments than the control. The weeds mainly emerged between mulching paper pieces and thus, the principal weed species was *M. vaginalis*, which is known to be resistant to herbicide. Based on the values of weed control, white paper mulching had a lower effect on weed control (96.8%) than paper and plastic mulching (more than 99%). In addition, there were no significant differences between mulching treatments and conventional practice (Table 1). These findings can be explained by the fact that, paper or plastic mulching retains the light transmittance, thereby inhibiting weed growth. Therefore, mulching technology can be used as the physically suppressed mechanism for weed control. Moreover, the high values of weed control in response to the plastic mulch treatments (average 99.75%) and conventional practices (99.7%) may have been due to the long term treatment of soil with herbicide prior to this experiment. It is important to consider these factors before applying mulching technology for rice cultivation in lieu of herbicide.

Paper mulching has the advantage of biodegradability and good weed control, but is expensive. Therefore, during the second season, we excluded paper mulching and instead employed a plastic film (20 µm) using partial tillage hairy vetch alone (PTHV) or in combination with barley (PTM). These treatments were also applied to save labor and increase weed suppression. The results showed that, the weeds associated with seeded rice were *M. vaginalis*, *L. prostrate*, *L. procumbens*, *C. difformis*, *E. kuroguwai*, *S. juncoides*, *Persicaria hydropiper*, *Aeschynomene indica* and *Fimbristylis miliaceae* (Table 2). Moreover, the treatment of plastic film mulching (20 µm) using hairy vetch mulch alone led to a significant decrease in the weed control percentage when compared to conventional practice or plastic mulching using hairy vetch in conjunction with barley. The percentage of weed control were amounted by 88.3% in the hairy vetch mulch alone treatment and 94.8% when hairy vetch was applied in combination with barley (Table 2). By contrast, the weeds dry weight was lower in the combined treatment of hairy vetch and barley (7.2 g m^{-2}) than in the hairy vetch mulch alone treatment (16.1 g m^{-2}). From the results obtained, we can conclude that plastic film or black paper mulch treatment reduced effectively weed emergence when green manure crops as hairy vetch alone or in combination with barley were applied. Seong et al. (2003) reported that, weed control values were high by barley straw incorporation under a barley-rice rotation cropping system and weed emergence was dramatically decreased. Moreover, rye grass applied as green manure had an allelopathic effect on tomato cultivation (Yu et at., 1995). These findings are attributed to the presence of allelopathic substances including organic acids derived from *gramineae* straw decomposition. During the first season, the plastic film mulching (20 µm) plot treatment resulted in 99.8% weed control when hairy vetch was incorporated during rice cultivation (Table 1). The density of grass weeds was lower in the mulch treatments during all stages of rice growth. Moreover, the addition of wheat residue mulch at 4 ton ha^{-1} and *Sesbania* intercropping for 30 days were equally effective at controlling weeds associated with dry-seeded rice (Singh et al., 2007). During the second season of the experiment, the percentage of weed control decreased to 88.3% under partial tillage hairy vetch treatment (Table 2). Our results indicate that, plastic film mulching is likely to increase weed control when applied over the long term in rice paddy soil.

Rice yield and its components

Rice yield and yield components during the first and second

Table 1. Numbers of dominant weeds, dry weight and weed control as affected by different mulching treatments (First season).

Treatments	Thickness (µm)	Occurrence of weeds[a] (Number per m^2)							Dry weight ($g\ m^{-2}$)	Weed control (%)
		Mv	Cd	An	Lu p	Lp	Ek	Ro		
Control	-	962	64.9	4.15	88.4	66.7	31.2	12.5	212.4	-
Conventional practice	-	9.2	0.0	0.0	3.2	4.3	0.0	0.0	0.65	99.7 a
Plastic Film mulching	20	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.34	99.8 a
Plastic Film mulching	10	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.59	99.7 a
Paper mulching (white)	10	57.2	3.9	0.0	11.1	0.3	0.6	0.6	6.91	96.8 a
Paper mulching (black)	10	9.4	0.6	0.0	1.4	1.4	0.0	1.9	2.49	98.8 a

Plastic film was removed at 41 days after transplanting (July, 13). [a] Mv, *M. vaginalis*; Cd, *C. difformis*; An, *A. keisak*; Lu p, *L. prostrate*; Lp, *L. procumbens*; Ek, *E. kuroguwai*; Ro, *R. indica*..

Table 2. Numbers of dominant weeds, dry weight and weed control as affected by green manure incorporation and plastic film mulching (Second season).

Treatments	Cultivation system[a]	Occurrence of weeds[b] (Number per m^2)							Dry weight ($g\ m^{-2}$)	Weed control (%)
		Mv	Lu p[b]	Lp[c]	Cd[d]	Ek[e]	Sj[f]	Etc[g]		
Conventional practice	CF	1.1	0.0	0.0	0.0	0.0	1.1	0.0	3.4	97.5 a
Plastic film (20 µm)	PTHV	9.9	0.0	0.1	4.5	0.0	3.0	1.1	16.1	88.3 b
	PTM	2.9	0.0	0.2	0.6	0.0	2.1	0.0	7.2	94.8 a
Without mulching	Control	67.8	4.4	0.2	45.6	5.6	60.0	51.1	173.2	-

Plastic film was removed at 38 days after transplanting (July, 13). [a] CF, Chemical fertilization; PTHV, partial tillage hairy vetch; PTM, partial tillage mixture. [b] Mv, *M. vaginalis*; Lu p, *L. prostrate*; Lp, *L. Procumbens*; Cd, *C. difformis*; Ek, *E. kuroguwai*; Sj, *S. juncoides*; Etc, *P. hydropiper*, *A. indica*, *F. miliaceae*.

seasons as affected by mulching treatments are summarized in Tables 3 and 4, respectively. During the first season, we evaluated the effects of paper color (white and black) and plastic film (10 and 20 µm) mulching on rice yield and its yield components. No significant differences in rice yield components were observed between treatment groups (Table 3). The white paper mulching treatment showed a higher increase in numbers of panicles, ripened grains and milled rice when compared with the black paper, but this increase was not significant (Table 3). The same trend was observed between plastic film treatments. This was likely due to the high level of nitrogen (109 kg N ha^{-1}) in the hairy vetch that was applied to the soil during rice cultivation. Moreover, 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 similar yield to that from the conventional practice treatment (Kim et al., 2002, Jeon et al., 2008). Plastic film (20 µm) mulch treatment led to an increase in milled rice (4,817 kg ha^{-1}) when compared with conventional practice (4640 kg ha^{-1}), but this increase was not significant (Table 3). Increased initial temperature, weed control and rice yield have been reported in response to plastic mulching (Liu et al., 2005; Tao et al., 2006).

Table 4 shows the effect of plastic film mulching (20 µm) using hairy vetch alone or in combination with barley on rice yield during the second season. The results showed that the plastic film with partial tillage hairy vetch alone (PTHV) treatment led to a significant increase in the number of panicles (341.1 m^{-2}) when compared with the conventional practice treatment (243.0 m^{-2}) or with partial tillage of hairy vetch and barley straw mixture treatment (PTM) (260.7 m^{-2}). Conversely, no significant differences were found between the PTM treatment and conventional practice or no mulch treatment (Table 4). Moreover, the number of spikelets per panicle decreased significantly in the plots of the plastic film mulching using the PTHV or PTM when compared with the conventional practice treatment. The percentage of ripened grain and 1000 grain weight did not differ

Table 3. Effects of paper mulching color (white or black) and plastic film thickness on rice yield and yield components (First season).

Treatment	Panicle (Number per panicle)	Spikelets (Number per panicle)	Ripened grain (%)	1000 grain Weight (g)	Milled rice (kg ha^{-1})
Conventional practice	303 a	79.3 a	94.2 a	20.1 a	4640 a
Paper mulching (black)	315 a	83.2 a	92.2 a	20.4 a	4528 a
Paper mulching (white)	358 a	81.8 a	93.8 a	20.2 a	4629 a
Plastic film (10 µm)	280 a	84.4 a	94.5 a	20.9 a	4573 a
Plastic film (20 µm)	325 a	77.6 a	92.8 a	20.7 a	4817 a

Table 4. Effects of green manure incorporation and plastic film mulching on rice yield and yield components (Second season).

Treatment	Cultivation system[a]	Panicle (Number per m^2)	Spikelets (Number per panicle)	Ripened grain (%)	1000 grain weight (g)	Milled rice[b] (kg ha^{-1})
Conventional practice	CF	243.0 b	93.0 a	91.0 a	19.9 a	4142 b
Plastic film (20 µm)	PTHV	341.1 a	78.5 b	90.8 a	20.0 a	4421 a
	PTM	260.7 b	87.4 b	91.6 a	19.8 a	4011 b
Without mulching	PTHV	336.7 a	59.7 c	91.1 a	19.2 a	2563 c
	PTM	201.5 b	63.6 c	87.5 b	20.4 a	2753 c

[a] CF, Chemical fertilization; PTHV, partial tillage hairy vetch; PTM, partial tillage mixture. [B] Milled rice of conventional practice; CF, plastic film (20 µm) PTHV and PTM were already published by Jeon et al. (2008).

significantly among treatments (Table 4). Furthermore, the rice yield (milled rice) was 4142 kg ha^{-1} in the conventional practice plot, which was not significantly different from the PTM treatment. Conversely, the PTHV treatment led to a significant increase in milled rice (4421 kg ha^{-1}) when compared with the conventional practice (4142 kg ha^{-1}). These findings were primarily attributed to early tiller establishment of rice plants. Moreover, barley had a high C/N ratio during the middle period of growth and caused N immobilization in the PTM treatment. Taken together, weed emergence was high enough to compete with rice in the control treatment (without mulching), resulting in a reduction of the rice yield. Singh et al. (2007) reported that mulch using wheat residues increased the grain yield of dry seeded rice by 22 and 17% in 2003 and 2004, respectively. Additionally, they found that the rice yields obtained using *Sesbania* and mulch was similar. On other hand, intercropping of *Sesbania* with rice can cause a reduction in rice yield. Furthermore, plastic film mulching resulted in a 12% higher average yield of rice, while wheat straw mulching led to a 14% lower average yield of rice when compared with lowland rice under traditional flooding (Liu et al., 2003). Based on the results of this study, the application of green manure crops with bioherbicidal characteristics would induce additional weed control and increased rice yield.

Changes in soil redox potential and ammonium (NH_4-N) concentration

During the second season, the influence of plastic mulch (20 µm) with PTHV or PTM on redox potential and ammonium (NH_4) concentration in paddy soil were also investigated. The results revealed that the soil redox potential (Eh) decreased in response to all treatments (Table 5). Plastic film mulching with PTHV or PTM mulch caused a dramatic reduction in soil Eh when compared with conventional practice (Table 5). Specifically, the highest Eh value (-71 mV) was recorded in the conventional fertilization plot three days after transplantation (DAT) when compared with mulching treatments. Moreover, the data collected in the second season showed that, rapid decreases in Eh values occurred within the first few DAT, especially for the PTM treatment (-147 mV after 3 days). Similarly, the Eh values decreased as the rice transplantation increased. The maximum decrease in redox potential was observed in the PTM treatment (-218 mV) at 17 DAT (Table 5). Overall, the redox potential values decreased in PTHV and PTM for plastic film or no mulch when compared with conventional practice. Specifically, the incorporation of hairy vetch alone or in combination with barley in plastic or no mulch led to a rapid decrease in Eh values (Table 5). This was mainly due to the decomposition of organic matter including hairy vetch or barley straw. These findings are in line with the results of Yang and Chang (2001) and Tanji et al. (2003), who found rapid changes in the redox potential in paddy soil as a consequence of the decomposition of soil organic matter including rice straw. The field data in the present study demonstrated that, Eh measurement can only indicate the progressive development of reducing conditions in paddy soils.

Table 5. Changes in soil redox potential (mV) as affected by green manure incorporation and plastic film mulching (Second season).

Treatment	Cultivation system[a]	Redox potential (mV)		
		3 DAT[b]	10 DAT	17 DAT
Conventional practice	CF	-71	-179	-199
Plastic film (20 µm)	PTHV	-127	-220	-210
	PTM	-147	-201	-218
Without mulching	PTHV	-101	-180	-200
	PTM	-114	-161	-213

[a] CF, Chemical fertilization; PTHV, partial tillage hairy vetch; PTM, partial tillage mixture. [b] DAT, Days after transplanting.

Table 6. Changes in soil NH_4-N concentration as affected by green manure incorporation and plastic film mulching (Second season).

Treatment	Cultivation system[a]	NH_4-N (mg kg^{-1})		
		15 DAT[b]	53 DAT	83 DAT
Conventional practice	CF	10.9 b	6.01 a	3.39 a
Plastic film (20 µm)	PTHV	22.4 a	5.55 a	3.57 a
	PTM	20.4 a	5.01 a	3.59 a
Without mulching	PTHV	9.7 b	3.60 a	3.41 a
	PTM	10.1 b	4.75 a	2.89 a

[a] CF, Chemical fertilization; PTHV, partial tillage hairy vetch; PTM, partial tillage mixture. [b] DAT, Days after transplanting.

Changes in soil ammonium nitrogen (NH_4-N) concentration in response to plastic mulching with PTHV or PTM treatment are presented in Table 6. The volatilization of ammonium was negligible in this experiment as the soil pH was 5.4. The concentration of NH_4-N increased significantly in soil that received PTHV and PTM treatments during the initial stage of plastic film mulching (15 DAT) and were found to be 22.4 and 20.4 mg kg^{-1}, respectively, when compared with the conventional practice treatment (10.9 mg kg^{-1}) (Table 6). Green manures can increase soil organic matter which provides nutrients such as NH_4-N to the soil. In this regard, the use of plastic film mulch with green manure may provide desirable conditions that lead to increase in NH_4-N concentration during organic matter decomposition. No significant differences were observed in the concentration of ammonium in soil in the PTHV and PTM treatments at 15, 53 and 83 DAT. At 15 DAT, the NH_4-N concentration was lower in the conventional practice and no mulch treatments when compared with the plastic mulching treatments. These findings could be attributed to the high density of weeds absorbing a high amount of soil nutrients such as NH_4-N. These results were confirmed by the lower concentration of NH_4-N after rice transplantation (53 or 83 DAT). Additionally, these findings implicate a temporary nitrogen starvation resulting from the PTM plot of barley straw, which had a high C/N ratio. Specifically, the redox potential of soil was lowest in the rice straw plus controlled release fertilizer (CRF) 80% plot during the tillering stage. Conversely, the NH_4-N in soil was highest in the rye plus CRF 80% at the tillering stage (Jeon et al., 2007).

Conclusion

Organic farming is a promising technology to reduce the use of chemical fertilizer and herbicide, especially for rice fields in Korea. Therefore, in this study, mulching technology during two seasons was evaluated in a field experiment. Specifically, the effects of green manure applied as an environmentally friendly management to reduce agrochemical impacts were evaluated. The results showed that, plastic film (10 or 20 µm) and black paper mulching with hairy vetch alone are more effectively controlled weeds and rice yield than the other treatments. Plastic film mulching induced a decrease in the soil redox potential in rice paddies due to the decomposition of soil organic matter such as hairy vetch alone or hairy vetch and barley mixture. Similarly, the concentration of ammonium nitrogen increased in PTHV and PTM treatments. The possibility of reducing the amount of chemical fertilizer, herbicide and costs through the integration of mulch technology and green manure crop mulch warrants further study.

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