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Weed Occurrence, Rice Growth, and Soil Temperature as Affected by Different Biodegradable Mulching Materials in Wet Seeded Rice

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ABSTRACT: In spite water direct seeding cultivation of rice has advantages in terms of laborsaving and cost-down, it demonstrates uneven seedling establishment and difficult weed management. To select an applicable mat for mulching system of water seeded rice, weed occurrence, growth and yield performances of rice, and soil temperature were evaluated in several kinds of biodegradable mulching material. Field studies were conducted at the experimental farm of National Crop Experiment Station in 1999 and 2000. Among the mats tested in 1999, Safer-mat had the greatest effect on inhibiting weed occurrence and Lawn-mat demonstrated the least efficacy of weed control (EWC) value. In Safer-mat treatment, *Ludwigia prostrata* was the dominant weed species but *Echinochloa crus-galli* was not observed. Different kinds of mulching material from the mats studied in 1999 were tested in 2000. Biodegradable polyester (PES) coated on the recycled paper for newspaper press (RP) treatments showed similar or higher EWC values than non-mulched broadcast seed rice with 2 times of herbicide application (BC-herbicide) and Safer-mat that was the most effective mat on preventing weed appearance in 1999. Immediately after mat mulching on the surface of paddy soil, five pregerminated rice seeds were manually sown in each 3cm-hole formerly punctured at 30×14 cm spacing in 2000. All the 3 kinds of mulching material tested in 2000 had better seedling stand than BC-herbicide treatment. Rice yield in PES coated with 10 thickness on RP (PES10 μm+RP) was a little higher than in BC-herbicide treatment but the former produced less panicles in unit land area than the latter. PES10 μm+RP demonstrated a great effect on raising soil surface temperature than non-mulching treatment throughout the period of seedling establishment.

Key words: rice, weed, soil temperature, mulching, water seeded rice, biodegradable polyester, recycled paper, Safer-mat, Lawn-mat

Korean rice farming system is composed of more than 90% of transplanting and the rest direct seeding cultivation in recent years. Direct seeded rice provides many profitable aspects than transplanted rice in the viewpoint of labor and cost input. However the former exhibits less stable and uniform growth and yield than the latter, which are remained to be solved.

Direct seeding cultivation technologies of rice have been classified into two major categories; dry and water seeding in Korea. Furrow drill seeding technology was recently introduced to combine the advantages of wet and dry seeding of rice (Park *et al.*, 1995). Dry seeded rice exhibits insufficient panicles per unit land area (Park *et al.*, 1989), difficult weed management (Kim, 1992), and difficult sowing caused by rainfall in seeding season, which limit the application of this technology in farm house. Recently, studies on partial tillage system in dry seeded rice are in progress to minimize the disadvantages described above.

Water broadcast seeded rice (WBSR), which occupies most of water seeding area in Korea, provides the simplest seeding method, prosperous early growth of rice plants, sufficient panicles, and easier weed control, as compared to dry seeded rice. Yield performance of WBSR is comparable to that of transplanted rice (Lee *et al.*, 1974; Kim *et al.*, 1987). However it demonstrates lack of uniform seedling stand, which resulted from different seeding rate in unit land area and uneven land preparation or water management during the period of seedling establishment. Even if the seeding rate per unit land area in a field is uniform spot by spot, the rice seeds subjected to anaerobic condition by local flooding require more time to emerge and show poor root elongation than those subjected to aerobic environment.

Kim *et al.* (1987) reported that rice varieties with better performances in emergence and seedling establishment at early growth stage produced more spikelets per unit land area at late developmental stage in WBSR. Furthermore, hill seeded rice was reported to demonstrate higher percentage productive tillers and more spikelets than row seeded rice or broadcast seeded rice (Won *et al.*, 1996). These reports put great emphasis on the status of seedling stand in water seeded rice. Status of seedling stand influences thereafter growth of rice plants such as tillering pattern, penetration of solar radiation into canopy, biomass production, plant lodg-

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ing, and yield. Therefore, number and status of seedling stand can be considered as the most important factors for stable growth and yield of rice in direct seeding cultivation.

Another difficulty in WBSR is weed control. Although weed management in WBSR is easier than dry seeded rice, competitive ability of weeds in WBSR is greater than in transplanted rice (Guh *et al.,* 1980). The threshold of weed germination or emergence starts with rice germination or emergence in WBSR whereas transplanted rice begins to grow earlier than weed species. The greater competitive ability of weeds than rice plants consequently gives rise to difficult weed management. In WBSR, weeds have been controlled mainly by herbicide applications, just likely in transplanted rice. But WBSR requires more herbicides and labor input for weed control than transplanted rice does (Kim, 1992; Song *et al.,* 1987). In WBSR, herbicides are generally applied at 10 to 15 days after seeding and at intermediate growth stage of rice plants. However, additional manual weed elimination is required to complete weed control. To make it worse, in WBSR, status of uneven seedling stand gives a difficulty in entering the field for manual weed elimination.

In recent years, studies on allelopathy are actively undergoing (Kim *et al.,* 1999b; Yu & Chung, 1997) and there have been attempts to employ allepopathic effect on weed control in rice. Kim et al. (1999a) established an identifying system of allelopathic effect in rice, introducing the inhibitory effect of rice germplasm on root elongation of a weed species, barnyard grass (*Echinochloa crus-galli*). It was also reported that rice seedlings grown in competition with weeds contained more allelochemicals in plant body than those grown without competition did (Kim *et al.,* 1999b). In spite of these recent studies on the allelopathy, satisfactory result for sufficient weed control by the effect was not obtained yet in the field condition.

Polyethylene (PE) mulching system has been applied mainly in upland crops such as soybean (Chung, 1984), red pepper (Lee & Yoon, 1975), and sesame (Lee *et al.,* 1986; Oh *et al.,* 1994; Park *et al.,* 1991). PE mulching cultivation provides weed control effect (Park *et al.,* 1991; Pyon, 1985) and increased water use efficiency (Eom *et al.,* 1990; Lee *et al.,* 1986; Oh *et al.,* 1994). Further, it induces raised soil temperature (Kim & Lee, 1985; Lee & Yoon, 1975; Park *et al.,* 1991; Oh et al., 1994) and minimized soil erosion (Oh *et al.,* 1992) in upland crop management. Also PE film mulching system in transplanted rice was estimated to provide the increase of soil temperature, higher water and nitrogen use efficiencies as well as the effect of weed control and yield increase (Peng *et al.,* 1999). However, the material used in above mulching system was PE that is non-biodegradable and potentially harmful to environment. Recently, there have been attempts to control weeds by applying recycled paper (Ueno et al., 1999; Lee *et al.,* 1999), which is a biodegradable mulching material.

In the previous studies, we estimated the possibility of mulching system for weed control without herbicide application and uniform seedling establishment in water seeded rice, using biodegradable materials. These experiments were conducted to estimate the effects of various biodegradable materials for mulching system on weed occurrence, soil temperature, and growth performance in water seeded rice under the field condition.

MATERIALS AND METHODS

The effect of mat mulching system on the inhibition of weed occurrence, soil temperature, and growth performance of rice were estimated at the experimental farm of National Crop Experiment Station, Rural Development Administration, Korea in 1999 and 2000.

Weed Occurrence Depending on Mulching Materials

In 1999, inhibitory effects against weed occurrence were estimated in five different kinds of mulching material with different fabric properties, using completely randomized block design with 3 replicates. According to mesh size and weight of mulching materials, 60 g-8 mesh, 40 g-8 mesh, 30 g-3 mesh, Safer-mat (Y&K Co., Seoul, Korea), and Lawn-mat (Korean Green Development Co., Seoul, Korea), which are biodegradable, were tested. The 60 g, 40 g, and 30 g in the former 3 kinds of mat represent their weights (g m^{-2}), and 8 mesh and 3 mesh stand for their mesh sizes. The main material comprising Safer-mat is wood pulp. Lawn-mat tested in this study had been utilized for the installation of lawn seed. The mats glued with 5 dry rice seeds beneath the mats at 30×14 cm spacing were installed on the surface of paddy soil that had been puddled one day before installation. On sampling the weeds in the field area of 0.5×0.5m, they were classified into each species at 30, 50 days after seeding (DAS) and combined at flowering of rice. Each of the sampled and classified weed species in the mat mulching and non-mulching treatments were oven dried at 75 to constant weight to determine efficacy of weed control, which was calculated by following equation.

$$\text{Efficacy of weed control (\%)} = (WM-WF)/WF\times 100$$

where, WM means weed dry weight (WDW) in weed management plot by herbicides or mat mulching and WF represents WDW in weed-free plot.

In 2000, weed occurrence in six different kinds of mulching material were compared to select cheaper and appropriate mulching materials that could be practically applied in

farm house. To apply and test the materials for mulching cultivation system in water seeded rice, SK Chemical Co., Ltd. (Suwon, Korea) developed biodegradable polyester film (PES) with 15 thickness (PES15 μm), 25-thick PES (PES25 μm), 10-thick PES surface-coated on one side of recycled paper for newspaper (PES10 μm+RP), 12-thick PES coated on one side of RP (PES12 μm+RP), and 14-thick PES coated on one face of RP (PES14 μm+RP) in 2000. We also tested recycled paper (RP) produced by Jeonju-Pop Co. (Jeonju, Korea) without film coating, which has been utilized for newspaper press. Completely randomized block design was applied with 3 replicates. Mulching materials tested in this study were installed on the surface of paddy soil without seeding of rice. Weeds taken in the field area of 0.5×0.5 m at 50 DAS were combined and oven-dried to stable weight to determine efficacy of weed control.

Among the mats tested above in 2000, PES25, PES-10 μm+RP, and RP were selected and tested again to monitor their inhibitory effects against weed appearance with time during rice cropping season. Weeds in mat-mulching and non-mulching treatments were taken from the field area of 0.5×0.5 m at 30, 50, 70 DAS, and at harvest, then oven-dried at 75°C to constant weight for the determination of efficacy of weed control. Completely randomized block design with 4 replicates was used.

In both years, weed management plot in non-mulched water broadcast-seeded rice received pyrazosulfuron-ethyl · molinate at 12 DAS and cyhalofop-buthyl · pendimethalin at 40 DAS.

Growth Performances of Rice Plants

The growth and yield performances of rice were compared in PES25 μm, PES10 μm+RP, and RP, which were selected among the mulching materials tested in the first study of 2000. Treatments were subjected to completely randomized block design with 4 replicates. Mats punctured with 3 cm-diameter at 30×14 cm spacing were mulched on the surface of paddy soil at 1 day after puddling and drainage. Five pre-germinated rice seeds were manually sown in each of the hole. Percentage of seedling stand was determined at 30 DAS. Tiller number was monitored at 30, 50, and 70 DAS, and panicle number was determined at 20 days after flowering (DAF). Rice yield and its components were determined from 5 m^{-2} of sample and 5 hills at maturity, respectively.

Changes of Soil Temperature by Mat Mulching

Soil temperature was monitored during the period of seedling establishment in the 3 kinds of mulching material, tested above for the determination of growth performances, and was compared to that in non-mulching treatment. Auto thermo-recorder (Model TR-71, Hans system), installed beneath mats at the mid-point of four hills of rice seedlings, monitored the temperature of soil surface hourly for 30 days after seeding.

All plots in 1999 and 2000 received 110 N ha^{-1}, 45 P ha^{-1}, and 57 K ha^{-1}. Nitrogen fertilizer was split applied with 40% at basal, 30% at 30 days after seeding and 30% at panicle initiation (PI). Potassium fertilizer was split applied with 70% at basal and 30% at PI.

Obtained data were analyzed following analysis of variance by SAS software package and means were compared by Duncan's multiple range test (DMRT).

RESULTS AND DISCUSSION

Weed Occurrence Depending on Mulching Materials

Efficacy of weed control (EWC) as affected by mulching materials in 1999 decreased with the progress of growth stage of rice plants (Fig. 1). This decrease in EWC was caused by the degradation of mulching materials. Specifically, Lawn-mat showed the lowest EWC value, and little difference was observed between Lawn-mat and weed-free treatments at flowering stage of rice because it did not maintain its original shape once soaked in water as tested in the previous study. Although Safer-mat, 60g-8mesh, and 30 g-3 mesh demonstrated higher EWC values at 30 days after seeding (DAS) than non-mulching broadcast seeded rice with 2 times of herbicide application (BC-herbicide) treatment, only Safer-mat showed higher EWC value than BC-herbicide at 50 DAS. It was estimated that 60 g-8 mesh,

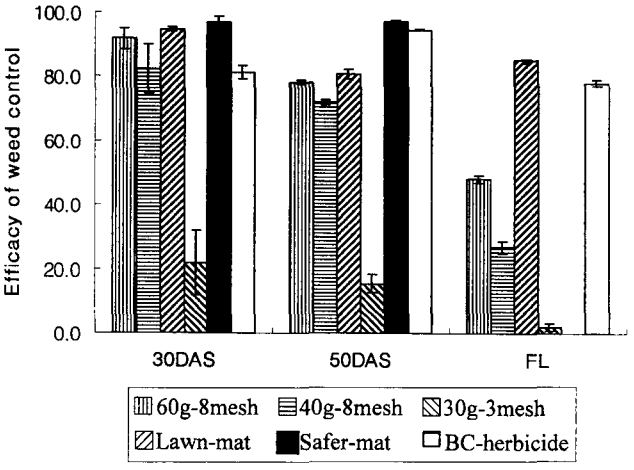

Fig. 1. Efficacy of weed control at three growth stages of water seeded rice as affected by different mulching materials in 1999. 60 g, 40 g, and 30 g represent g weight m^{-2}, and 8 mesh and 3 mesh mean mesh sizes of the mats. BC-herbicide is non-mulching broadcast seeded rice with 2 times of herbicide application. DAS and FL mean days after seeding and flowering stage of rice, respectively.

Table 1. Distribution (number) of weed species appeared at 30 days after seeding as affected by mulching materials in water seeded rice of 1999.

Mat† Weed species	60 g-8 mesh	40 g-8 mesh	30 g-3 mesh	Lawn-mat	Safer-mat	BC-Herbicide
Echinochloa crus-galli	9b	11 b	7b	29a	0b	3b
Leersia japonica	16a	24 a	15a	15a	0a	4a
Ludwigia prostrata	128b	145 b	23b	491a	63b	28b
Persicaria hydropiper	15b	23 b	5b	149a	8b	4b
Eleocharis kuroguwai	3a	11 a	3a	13a	7a	3a
Sagittaria pygmaea	5b	1 b	0b	13ab	1b	0b
Cyperus amuricus	7c	25 a	13ab	13ab	5c	24a

†Sixty g, 40g, and 30g represent g weight m^{-2}, and 8mesh and 3mesh mean mesh sizes of the mats. BC-herbicide is non-mulching broadcast seeded rice with 2 times of herbicide application. Same letters in a row are not significantly different by DMRT (P=0.05).

Table 2. Distribution (number) of weed species occurred at 50 days after seeding as affected by mulching materials in water seeded rice of 1999.

Mat† Weed species	60 g-8 mesh	40 g-8 mesh	30 g-3 mesh	Lawn-Mat	Safer-Mat	BC-Herbicide
Echinochloa crus-galli	8c	28a	5cd	21b	0d	4cd
Leersia japonica	16d	163b	0d	240a	0d	40c
Ludwigia prostrata	272b	296b	15d	429a	161c	284b
Persicaria hydropiper	208b	224b	56c	497a	59c	12d
Eleocharis kuroguwai	20c	57a	0d	40b	0d	0d
Sagittaria pygmaea	0b	0b	3b	40a	0b	0b
Cyperus amuricus	12b	13b	16b	52a	3c	0c

†Sixty g, 40 g, and 30 g represent g weight m^{-2}, and 8 mesh and 3 mesh mean mesh sizes of the mats. BC-herbicide is non-mulching broad cast seeded rice with 2 times of herbicide application. Same letters in a row are not significantly different by DMRT (P = 0.05).

40 g-8 mesh, and 30 g-3 mesh weakened as they degraded by the progress of time. Weed species appeared at late developmental stage of rice in BC-herbicide treatment resulted in lower EWC value than 30 g-3 mesh at flowering stage of rice. It was considered that Safer-mat treatment, discarded at 50 DAS because of poor seedling stand and growth of rice, was the most effective mat for the inhibition of weed occurrence among the mats tested in this study.

At 30 DAS, prosperous weed occurrence was observed throughout all the species in Lawn-mat treatment and Safer-mat treatment demonstrated comparable weed occurrence to BC-herbicide (Table 1). Although 60 g-8 mesh, 30 g-3 mesh, and 40 g-8 mesh treatments demonstrated higher or comparable EWC values to BC-herbicide at 30 DAS (Fig. 1), they showed more weed occurrence than BC-herbicide treatment (Table 1). More weed occurrence in those treatments potentially reduced their effects on the inhibition of weed occurrence, which was crystallized at 50 DAS (Table 2). At 50 DAS, less weed occurrence in Safer-mat than in BC-herbicide treatment finally contributed to the highest EWC value (Table 2 vs. Fig. 1). Although *Ludwigia prostrata* was dominant, *Echinochloa crus-galli*, which is the most harmful to rice growth, did not appear in Safer-mat treatment. *Ludwigia prostrata* and *Persicaria hydropiper* were dominant in 60 g-8 mesh, 40 g-8 mesh, and Lawn-mat whereas *Ludwigia prostrata* was dominant in BC-herbicide. Comparable weed occurrence was observed between 30 g-3 mesh and BC-herbicide plots but the former demonstrated lower EWC value than the latter (Table 1 vs. Fig. 1). As a consequence, Safer-mat demonstrated the most effective weed control without herbicide application and Lawn-mat showed the lowest EWC value in 1999.

In 2000, inhibitory effect of weed occurrence was estimated in different kinds of mulching material from 1999. As comparing EWC at 50 DAS, biodegradable polyester film (PES) coated treatments on recycled paper (RP), regardless of the coated thickness, demonstrated a little higher value but not significant differences from Safer-mat, which showed the highest EWC value in 1999, and BC-herbicide treatment (Fig. 2). Rainfall and irrigation considerably weaken physical strength of RP to prevent weeds after mat installation in the field, which resulted in the lowest EWC value. PES15 and PES25 without coating on paper sheet had less inhibitory effect on the weed occurrence than PES

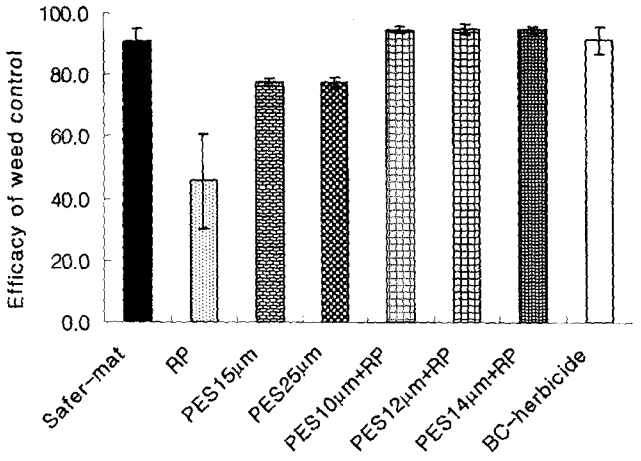

Fig. 2. Efficacy of weed control at 50 days of sowing in different biodegradable mulching materials in 2000. RP is recycled paper for newspaper press and PES is biodegradable polyester. BC-herbicide means broadcast seeded rice with 2 times of herbicide application.

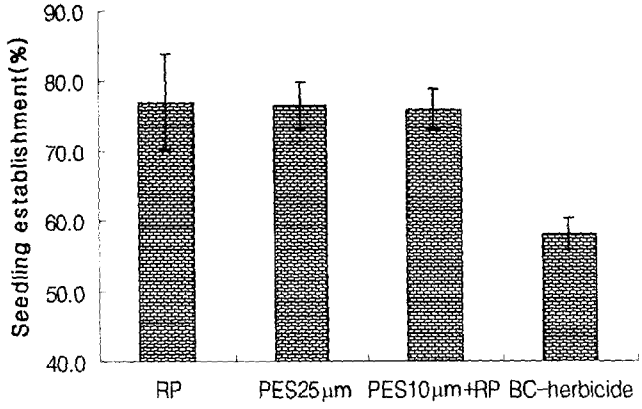

Fig. 3. Efficacy of weed control at different growth stages of rice plants in three kinds of mulching material. RP and PES mean recycled paper for newspaper press and biodegra dable polyester, respectively. BC-herbicide stands for broadcast seeded rice with 2 times of herbicide application. DAS is days after seeding.

coated treatments on RP. Lower EWC value in PES film treatments without RP resulted from their texture like polyethylene film, which has poor adsorption to soil surface. Consequently, the mat with PES film coated on RP could substitute for Safer-mat to prevent weed occurrence physically in a low cost.

Among the mats tested in the first experiment of 2000, PES25 μm, PES10 μm+RP, and RP were selected for the second study to monitor their effects on weed occurrence and rice growth. The weed occurrence and growth performances of rice in the selected mats were compared to those in BC-herbicide. As depicted in Fig. 3, RP and PES25 demonstrated lower EWC value than BC-herbicide throughout the growth stage of rice plants. The gap of EWC between both mats and BC-herbicide turned greater with the proceeding of developmental stage of rice. Especially, RP with similar degree of EWC at 30 DAS showed considerably lower EWC value than BC-herbicide from intermediate developmental stage of rice, suggesting its rapid degradation as evidenced in the first experiment of 2000. PES25 revealed the lowest EWC among the treatments throughout the stages of rice plants. This was caused by its polyethylene-like texture, which has poor adsorption to soil surface. Among the mats, only PES10+RP had greater effect in preventing weed occurrence than BC-herbicide treatment (Fig. 3). It had a lucrative property adsorbing to soil surface due to being coated on paper, which contributed to the space elimination between mat and soil surface. Furthermore, PES film coated on RP could considerably inhibit weed occurrence and maintain the mats strength in the paddy field.

Growth Performances of Rice Plants

Immediately after mat installation, in 2000, five pregerminated rice seeds were manually sown in each 3cm-diameter hole punched formerly at 30×14 cm spacing. Difference of percentage seedling establishment among the mulching materials was fairly small, but all the mulching treatments had higher percentage of seedling stand than BC-herbicide (Fig. 4). By means of puncturing the mat and seeding in the holes, instead of attaching dry seeds beneath mat, emergence and seedling establishment of rice improved dramatically (Data not shown).

At 30 DAS, little difference in tillers per unit land area was detected among the treatments (Fig. 5). However, less tillers and panicles were produced in RP and PES25 than in PES10+RP and BC-herbicide because of the prosperous

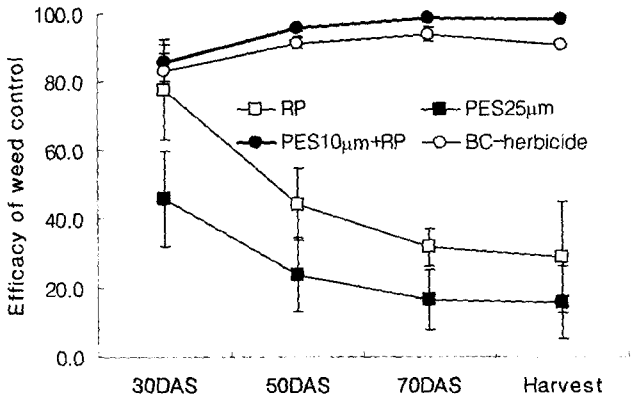

Fig. 4. Seedling establishment in different mulching materials and non-mulched water broadcast seeded rice of 2000. RP and PES mean recycled paper for newspaper press and biodegradable polyester, respectively. BC-herbicide stands for broadcast seeded rice with 2 times of herbicide application.

weed growth in the treatments (Fig. 5 vs. Fig. 3). PES10+RP treatment showed little difference in tiller number at 50 and 70 DAS from BC-herbicide. But a little more panicles per unit land area was produced in BC-herbicide than PES10 μm+RP. It was estimated that less panicles in PES10 μm+RP, not competing with weeds, than non-mulched treatment was caused by the loss of nitrogen (N) applied onto mat at tillering stage of rice plants, apart from N incorporated into soil at basal and N supplied after the degradation of mats at PI. Therefore, establishment of reasonable N split application method might be a next research step for mat mulching cultivation of rice.

In 2000, PES10 μm+RP treatment obtained the highest yield in milled rice although there was no significant difference in yield between PES10+RP and BC-herbicide (Table 3). Comparatively low yields in the other 2 kinds of mat resulted mainly from decreased panicles per unit land area, which was caused by severe competition of rice plants with prosperous weed appearance. In PES10+RP treatment, it is expected that more panicles than in current N split application method (40% at basal-30% at tillering-30% at PI) would be produced by amended N management system for mulching cultivation of water seeded rice.

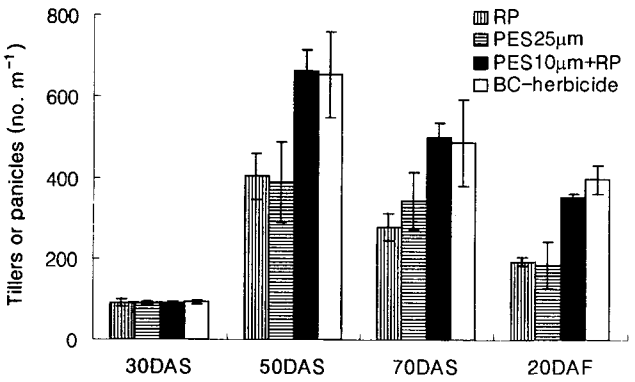

Fig. 5. Tillers at 30 days after seeding (DAS), 50DAS, and 70DAS and panicles at 20 days after flowering (DAF) as affected by mulching materials in water seeded rice of 2000. RP and PES mean recycled paper for newspaper press and biodegradable polyester, respectively. BC-herbicide stands for broadcast seeded rice with 2 times of herbicide application.

Changes of Soil Temperature by Mat Mulching

Hourly average soil temperature monitored for 30 DAS was higher in PES10+RP and PES25 than in non-mulching (NM) treatment while that in RP had little difference from NM (Fig 6). It is considered that PES having a similar texture to polyethylene gave rise to greenhouse effect that raises air temperature in a greenhouse.

The effect on raising soil temperature of PES25 was the greatest during the first 10 days after seeding and it turned

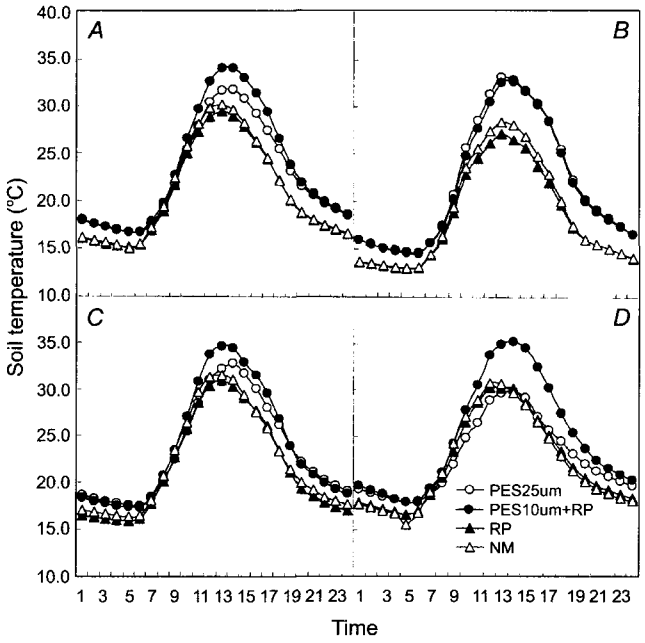

Fig. 6. Hourly average soil temperature during the period of seedling establishment of mat-mulching and non-mulching treatments in water seeded rice. Hourly average soil temperature (HAST) for 30 days after seeding (A), HAST for 10 days after seeding (B), HAST for following 10 days of B (C), HAST for following 10 days of C (D). RP, PES, and NM mean recycled paper for newspaper press, biodegradable polyester, and non-mulching treatment, respectively.

Table 3. Yield performances in 3 kinds of mulching material and non-mulched broadcast seeded rice with two times of herbicide application in 2000.

Mat†	Panicle no. m^{-2}	Spikelet no. per panicle	Grain filling (%)	1000-grain wt. in brown rice (g)	Yield in milled rice	Yield index
PES10 μm+RP	352a	120ab	69.0a	18.4a	4.90a	105
PES25 μm	186b	131a	57.7a	17.9b	2.81b	60
RP	195b	97b	67.5a	18.2ab	3.01b	64
BC-herbicide	397a	102ab	65.5a	18.3a	4.68a	100

†PES and RP are biodegradable polyester and recycled paper for newspaper press, respectively. BC-herbicide means non-mulched broa d-cast seeded rice with 2 times of herbicide application. Same letters in a column are not significant by DMRT ($P = 0.05$).

less with time because of poor adsorption to soil surface, while that of PES10+RP was maintained for longer period. Raised soil temperature in PES25 μm and PES10 μm+RP was observed not only during daytime but also during night.

This raised soil temperature might give a positive effect on root elongation and top growth of rice plants, which should be tested in the next study. Moreover, it is expected that PES10 μm+RP could expand the farming area of water seeded rice to northern region of Korea where the temperature is relatively low for direct seeding cultivation.

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