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Effect of Recycled Paper Mulch on Yield of Fall-grown Potato

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ABSTRACT : High temperature during sprout emergence period of potato (*Solanum tuberosum* L.) is a major limitation to the yield of fall-grown potato in Korea. To explore the possibility of improving the yield of fall-grown potato through recycled paper mulching, the changes of soil environment and the growth and yield of potato cv. Daeji as affected by three mulching treatments of non-mulched control, recycled paper mulching (RPM), and black polyethylene film-mulching (BPFM) were examined over two fall seasons at Suwon, Korea. The mulching materials were a recycled mulch paper with 110 g/m^2 and a thickness of 0.1 mm, which was manufactured from old corrugated containers for this experiment and a commercial black polyethylene film with a thickness of 0.01 mm. On an average throughout the growing period, the soil temperature with RPM at the 5-cm depth was lower by 0.4-1.1°C than that of the control. The maximum temperature during daytime in RPM was lowered by approximately 1 to 5°C according to the weather condition during emergence period, the difference being great on a fine day. The soil temperature with BPFM was much higher than the control. The effect of the mulching treatments diminished as the canopy became developed. The mulching treatments were more advantageous than the control in the conservation of soil water. Moreover, RPM and BPFM efficiently suppressed the occurrence of weeds until the potato harvest. RPM improved the emergence significantly due to lower soil temperature, whereas BPFM showed much poorer emergence than the control. Growth after emergence and yield were significantly higher in RPM than in the control and BPFM. It was concluded that the significantly improved yield in RPM compared to that in the control was mainly due to the improvement of the sprout emergence and tuber growth accompanied by lower soil temperature and better conservation of soil water.

Since the fall season potatoes, in general, are sequentially cropped with spring vegetables in Korea, they are planted on late July or early August when the temperature and humidity are at the highest. Thus, seed potatoes easily decay and poor initial growth is resulted (Kang 1970). If planting is delayed further, sufficient growth period cannot be secured due to frost. The increased planting density to secure the plant population as well as the rice straw mulching treatment were suggested to be effective in solving such a problem (Choi & Cho 1978). However, rice straw is not available at the time of planting in fall-season potato, as it is preferred as animal feed.

Recent studies have shown that RPM could be used as an alternative to other organic mulches like straw and plastic films, one of the major factors contributing to the contamination of agricultural environments, in several crops. Paper-mulching treatment resulted in a suppressed weed occurrence during the initial stage of crop growth as well as a lower soil temperature than the non-mulching treatment in rice (Lee *et al.* 1997; 1998; Umezaki & Tsuno 1998) and summer garden plants (Anderson *et al.* 1995). The growth of summer garden plants including tomatoes was delayed by lowering the soil temperature through the paper-mulching treatment (Anderson *et al.* 1995).

RPM may be one of the useful crop production technologies to minimize damages caused by high temperature to the fall season potato in Korea. However, the effect of RPM on potato crop has not yet been addressed. The objectives of the present study thus were to examine the effects of RPM on the soil environments and the growth and yield of fall-grown potatoes.

MATERIALS AND METHODS

Field experiments were conducted over two years, 1997 and 1998 on a loamy soil at the Experimental Farm (37°16'N, 126°59'E) of Seoul National University in Korea, where the soil was relatively low in organic matter, CEC, and soil nitrogen. The mean and maximum air temperature and rainfall during the potato growth period were collected from the official meteorological station located within 500 m from the experiment site. As shown in Fig. 1, Rainfall occurred mainly on early August, and the mean and maximum air temperature was approximately 25°C and 30°C, respectively, when the potatoes were planted.

Potato cultivar 'Daeji' was used for the two years. Potatoes were cut into several pieces of about 60 g each, healed the wound for several days in a cool place, and the pre-

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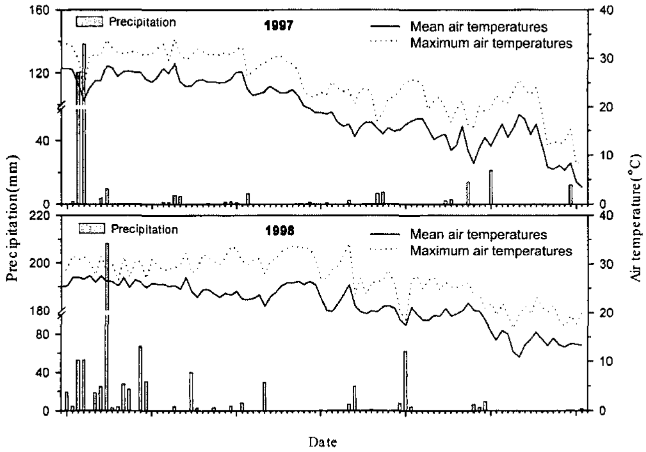

Fig. 1. Daily precipitation and mean and maximum air temperatures during the growth period of fall season potato from July 1 to October 31.

sprouted pieces were planted. On 11 August 1997, seed potatoes were planted at a spacing of 35 cm × 25 cm. Fertilizers were applied basally at a level of 150 kg of N, 100 kg of P, and 120 kg of K per hectare. On 20 August 1998, seed potatoes were planted at a spacing of 30 cm × 30 cm. Basal fertilization of 150 kg of N, 100 kg of P, and 100 kg of K per hectare were also applied.

Experiment treatments

The experiments comprised three mulching treatments with recycled paper and black polyethylene film, and a non-mulched control. The recycled paper, 110 g/m^2 with a thickness of 0.1 mm, was manufactured from old corrugated containers for this experiment (Dongil Paper Manufacturing, Inc., Seoul, Korea). Black polyethylene films were 0.01 mm thick. The experimental plots were arranged in a randomized complete block design with three mulching treatments randomized inside each of three blocks (replicates). A mulching treatment plot inside each block was a row with the area of 0.6 m × 30 m (18 m^2), where 240 pre-sprouted potato pieces were planted in 1997 and 200 pre-sprouted potato pieces in 1998. Mulching materials were covered just after planting, and cut at the spots where potatoes were planted in the form of a cross (5 cm), enabling the potato sprouts to emerge.

Measurements

Sprout emergence was recorded every other day starting from one week after planting. For the determination of shoot dry weight, root dry weight, leaf area index, and fresh tuber weight, all the plants from 1.5 m × 0.6 m (0.9 m^2) of each row were dug out on six dates in 1997, from 28 August to 3 October and on five dates in 1998, from 3 September to 7 October. Four plants of average size were selected and separated into root, stem, leaf and tuber. Leaf area index was measured using a CI2003 laser area meter (CID Inc., USA). All the plant components except tuber were oven-dried at 80°C for two days and weighed. Fresh weight was measured for tuber. The measured values of four plants were transformed into the values per unit area by considering the planting density and the percentage of sprout emergence. Potato was harvested on 13 October in 1997 and on 15 October in 1998. Tuber yield of potato was determined with the samples taken from 6 m × 0.6 m (3.6 m^2) in each row, excluding tubers smaller than 2 cm in diameter. Plant growth and tuber yield were not measured for the BPFM in 1997 because sprout emergence was too low to secure optimum size of sample and to compare those properly with other treatments.

Thermocouples (chromel-alumel) were placed at 5 and 10 cm depths from the soil surface, and average values were recorded at a 10-minute interval using a CR10 data logger (Campbell Inc., USA). Soil moisture content was also measured gravimetrically at 10-day intervals in 5-cm increments up to 15 cm depth.

For the evaluation of decomposition process, three pieces of 10 × 10 cm were cut periodically from the mulched papers, washed with water, dried for two days in a dry oven of 80°C, and weighed. Weed occurrence and weed dry weight were measured 30 days after planting.

RESULTS

Soil temperature and moisture

During the sprout emergence and early growth stage, the soil temperatures varied greatly among different mulching treatments and the effects of mulching treatments on soil temperature was different between the two years of 1997 and 1998 (Fig. 2 and Fig. 3). Fig. 2 shows the diurnal variations in soil temperature for 5 days immediately after planting. In 1997, the soil temperature of RPM was significantly lower than that of the control or BPFM. The maximum soil temperatures of RPM were lower by approximately 1 to 5°C than those of the control according to weather condition, the differences being greater on sunny days. BPFM showed little differences in maximum soil temperatures from the control, but a little higher minimum temperature. In 1998 when the planting time was somewhat late and it had much rains just after planting (Fig. 1), the soil temperature of RPM was much lower than that of BPFM, but was not greatly different from that of the control.

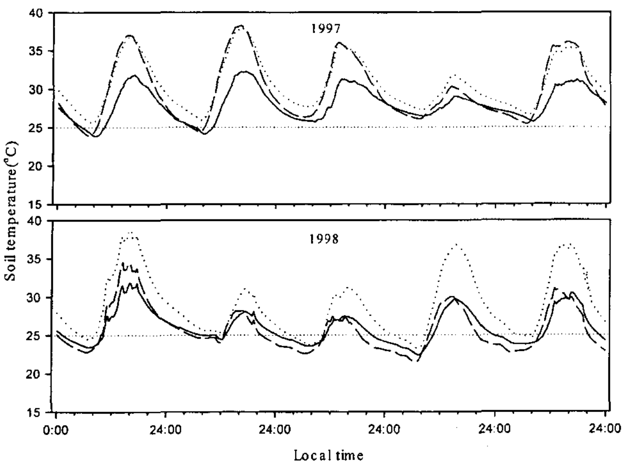

Fig. 2. Diurnal variation in soil temperature at 5 cm depth as influenced by mulching treatment during the potato emergence period from 16 to 20 August 1997 and 22 to 27 August 1998 (—— : mulch paper, ‥‥ : black polyethylene film, - - - : bare soil).

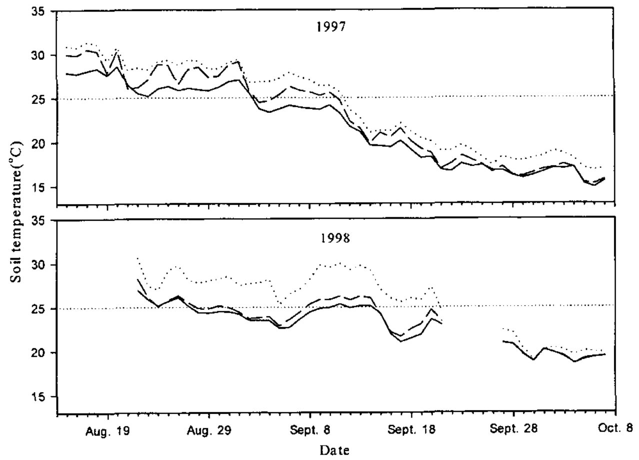

Fig. 3. Daily mean soil temperatures at 5 cm depth as influenced by the type of mulch applied during the growth period of fall season potato in 1997 and 1998 (—— : mulch paper, ‥‥ : black polyethylene film, - - - : bare soil).

As in Fig. 2, the average soil temperature of RPM over the whole growth period was 21.8°C in 1997, which was lower than that with BPFM and the control by 2.3 and 1.1°C, respectively. In 1998, the average soil temperature of the soil with RPM was 23.0°C, which again was lower than that of BPFM and the control by 2.9 and 0.4°C, respectively. The effects of the mulching treatments on soil temperature diminished as the crop cover became established.

Soil moisture was affected substantially by the mulching treatments and the weather condition. In 1997 when there was only a small amount of rainfall during the growing period (Fig. 1), a significant difference in the moisture contents among the treatments was observed (Table 1). The soil moisture contents at 0-5 and 5-10 cm depths were the highest in BPFM, and the lowest with the control. The soil moisture contents in RPM were significantly higher than in the control and slightly lower than in BPFM. Contrary to this, no significant difference among the treatments was observed except for the measurements on October 9 in 1998 when the rainfall distribution was even and there was a large amount of rainfall (Fig. 1).

Decomposition of mulching paper and occurrence of weeds

No yearly variation in decomposition process of the mulched papers was observed between 1997 and 1998 (Fig. 5). The mulched papers decomposed slowly, with more than 90% remaining for about 50 days. Accordingly, weed occurrence was suppressed until the potato harvest. At 30 days after planting, a large amount of weeds were harvested from the patches (weed not controlled) of the control plot (357 and 180 g/m^2 in 1997 and 1998, respectively), while no weeds were observed in the plots with RPM and BPFM.

Table 1. Soil moisture content (%) as influenced by mulching treatment during growth period of fall season potato culture.

Soil layer and treatment	1997				1998			
	Aug.31	Sep. 9	Sep.19	Sep. 30	Sep. 7	Sep. 22	Oct. 9	Oct. 16
0-5 cm soil depth								
Paper	21.5	16.6	17.8	17.5	23.3	20.4	20.6	25.6
Black polyethylene	22.6	22.6	22.4	24.1	26.9	25.0	22.8	26.3
Non-mulched	14.8	12.1	13.0	16.7	23.4	24.6	15.2	23.9
S.E.	0.44	0.82	1.05	1.55	3.21	2.51	0.76	1.57
5-10 cm soil depth								
Paper	26.6	25.9	21.4	22.0	27.9	25.6	23.9	29.4
Black polyethylene	28.6	27.3	25.4	28.2	28.3	27.9	25.9	27.2
Non-mulched	23.3	20.6	19.9	18.9	26.1	27.7	19.3	23.2
S.E.	1.30	1.56	1.39	0.60	5.88	2.86	1.07	2.79

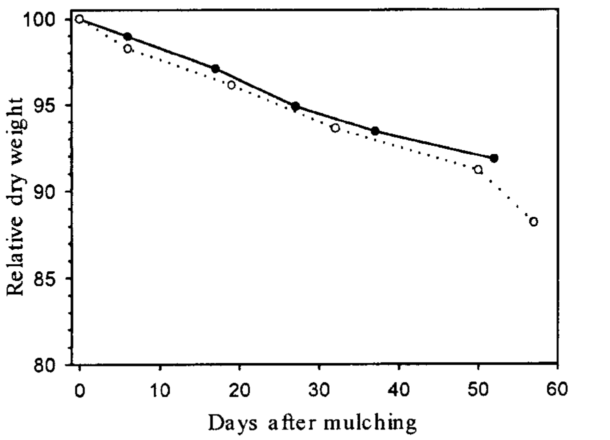

Fig. 4. Degradation of mulching paper over the field in 1997 (– ● –) and 1998 (···○···).

Table 2. Sprout emergence (%) in fall season potato as affected by mulching treatment.

Mulching treatment	Year	
	1997	1998
Recycled paper	82.7	95.6
Black polyethylene	14.5	42.8
Non-mulched	31.8	92.1
S.E.	1.50	3.29

Sprout emergence, growth and yield

The sprout emergence of potato was affected significantly by the mulching treatments. In 1997, the percent sprout emergence was very low since seed potato decayed due to high soil temperature in the control and BPFM (Table 2). However, in RPM, the sprout emergence was higher than those of the other treatments; less decay of seed potatoes occurred as a result of the lowered soil temperature. In 1998, the sprout emergence increased compared to 1997 in all treatments due to the lower soil temperature during sprout emergence in 1998. The sprout emergence was higher than 90% in the control and RPM, while it was less than 50% in BPFM.

The potato growth was significantly affected by mulching treatments throughout the growing period (Table 3). When compared to the control, RPM resulted in an increase in shoot dry weight, root dry weight, leaf area index, and tuber weight in both years. The bulking of potato tubers in RPM started about 7 days earlier than in the control in 1997 and at the same time as in the control but about 7 days earlier than in the BPFM in 1998. Growth was the lowest in BPFM in both years.

The mulching treatments exerted substantial effects on the yield of potato (Table 4). Potato yield was increased significantly by RPM and decreased remarkably by BPFM in both years. In 1997, the yield of RPM was double that of the control. In 1998, the yield of RPM was the highest, whereas that of BPFM the lowest. The yield of BPFM was merely 30% of those of the control and RPM.

Relationship of soil temperature with sprout emergence and tuber growth

Sprout emergence was related with the average soil tem-

Table 3. Leaf area index, shoot dry weight (g/m^2) and tuber fresh weight (g/m^2) as affected by mulching treatment.

Plant part and treatment	1997			1998		
	Aug. 29	Sep. 20	Oct. 4	Sep. 3	Sep. 21	Oct. 7
Leaf area index						
Mulch paper	0.4	2.8	3.1	0.4	4.0	6.7
Bare	0.1	0.9	1.8	0.4	3.6	4.9
Black polyethylene	-†	-	-	0.1	1.0	2.9
S.E.	0.01	0.22	0.18	0.03	0.07	0.61
Shoot dry weight						
Mulch paper	26.6	227.3	203.0	32.8	253.3	443.3
Bare	6.0	61.9	99.2	28.6	216.9	357.4
Black polyethylene	-	-	-	6.9	61.7	211.0
S.E.	0.88	18.40	17.43	2.33	3.55	27.45
Tuber fresh weight						
Mulch paper		348.2	1438.9	0.0	215.6	2106.3
Bare		23.0	632.8	0.0	100.8	1543.4
Black polyethylene	-	-	-	0.0	0.0	603.1
S.E.		52.68	100.49	0.00	12.88	109.77

†Due to extremely low sprout emergence, plant growth was not measured.

Table 4. Fresh tuber yield (t/ha) at harvest in fall-grown potato as affected by mulching treatment.

Mulching treatment	Year	
	1997	1998
Paper	1.42	2.37
Black polyethylene	-[†]	0.74
Non-mulched	0.77	1.97
S.E.	0.049	0.160

[†]Due to extremely low sprout emergence, yield was not measured.

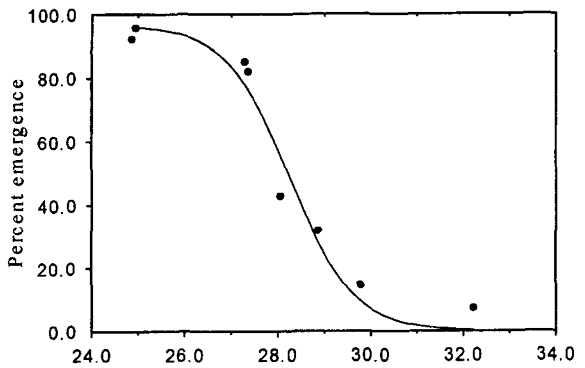

Fig. 5. The relationship between percent sprout emergence and mean soil temperature at 5 cm depth during 12 days after planting in fall season potato. Two points were included from the preliminary tests with transparent plastic film and recycled mulch paper in 1996.

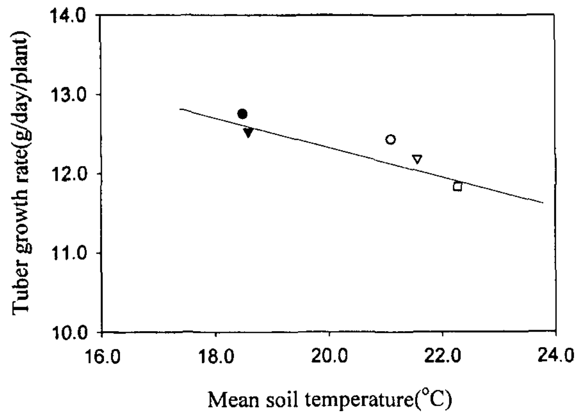

Fig. 6. The relationship between tuber growth rate and mean soil temperature at 10 cm depth during tuber growth period (Y= –0.18X+15.9, r= –0.891). The symbols show mulching treatments (▼ : '97 paper mulch, ● : '97 bare soil, ▽ : '98 paper mulch, ○ : '98 bare soil, □ : '98 black polyethylene film).

perature at 5 cm depth during 12 days after planting (Fig. 5). Within the soil temperature range of 25 to 32°C, sprout emergence showed a noticeable inverse relationship with soil temperature. Sprout emergence was highest around 25°C, and rapidly decreased with further increase of soil temperature. To avoid the confounded effect of plant population, tuber growth rate of individual plant was related to the mean soil temperature at 10cm during the bulking period of potato tuber (Fig. 6). Within the soil temperature range of 18°C to 22°C there was a negative linear relationship between soil temperature and tube growth rate.

DISCUSSION

For the fall season potato culture in Korea, it is important to enhance the sprout emergence of potato since the seed potatoes decay easily due to high soil temperature during planting season (Kang 1970). In general, RPM substantially reduced soil temperature during the daytime, whereas BPFM raised the soil temperature during day and night (Fig. 2, Fig. 3). However, the effects of RPM and BPFM on soil temperature were different between the two experimental years when the distribution and amount of rainfall were different during potato growing period; there were more frequent rains and greater amount of rainfall in 1998 than in 1997, and thus soil moisture contents were higher throughout growing period in 1998 (Table 1). In 1997 when there was less rainfall and soil was drier, soil temperature of 5cm depth in the daytime rose almost up to 39°C in the control on some fine days (Fig. 2). As soil heat conductivity is lower in drier soil, downward heat flow is obstructed and heat accumulates in the upper soil layer during daytime, resulting in higher soil temperature (Manrique 1988; Monteith & Unsworth 1990). In 1998 with more cloudy days and higher soil moisture, soil temperature seldom exceeded 30°C in the control even though air temperature was not different so greatly (Fig. 1). As non-transparent coverings like paper obstructed the downward flux of radiation onto the soil surface, RPM greatly reduced the soil temperature compared to the control on fine days in 1997 and in 1998. On the contrary to RPM, the soil temperature was markedly raised by BPFM compared to the control. The soil temperature differences were greater in 1998 than in 1997. The effects of the mulching treatments on soil temperature diminished as the soil surface became increasingly shaded with canopy development (Fig. 3)

The mulching treatments clearly improved the soil moisture compared to the control, since evaporation was obstructed due to the soil covering. Soil moisture contents were a little higher in BPFM than in RPM. This might be caused by higher transpiration due to the increased plant growth in RPM as in Table 3.

The sprout emergence was very low in the control in 1997 and in BPFM in the both years of experiment, while RPM showed higher emergence than the other treatments in both years (Table 2). The differences in sprout emergence among the mulching treatments could be attributable to the altered soil temperature due to mulching treatments. Sprout emergence showed a inverse relationship with soil temperature at 5 cm during 12 days of sprout emergence, being highest around 25°C (Fig. 5). The optimum soil temperature for emergence was reported as 21.1-23.9°C at 10 cm depth (Yamaguchi *et al.* 1964) and as 25°C at 5 cm depth (Midmore 1984).

There was a great difference in the subsequent plant growth after emergence according to the changes not only in plant populations but also in the plant growth rates caused by different soil environments due to mulching treatments (Table 3). Growth and yield were increased notably in RPM with a high plant population due to the improved emergence compared to those of the other treatments. Higher yield from the RPM was not only caused by the improved emergence but also by the earlier and rapid tuber growth due to lower soil temperature. The growth rate of tuber showed a negative linear relationship with mean soil temperature during tuber bulking period (Fig. 6). Gregory (1956) also reported that at high air temperature of 30/24°C (day/night) high soil temperature decreased the tuberization and the tuber weight as well.

It was concluded that the lowered soil temperature, preservation of soil water and suppression of weed occurrence through RPM were favorable factors for the growth and yield of potato. RPM may contribute to the potato production in fall season of temperate region and tropics as well.

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