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Growth and Yield of Spring-Grown Potato under Recycled-Paper Mulching

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ABSTRACT: To explore the feasibility of recycled paper mulching in spring-grown potato the changes of soil environments and the growth and yield of potato under non-mulched control and three mulching treatments of recycled paper (RPM), transparent polyethylene film (TPFM), and black polyethylene film (BPFM) were examined over two spring seasons in 1998 and 1999 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 the commercial polyethylene films with a thickness of 0.01 mm. RPM lowered the average soil temperature at 5-cm depth during the potato growing period by 0.3°C compared with the control, whereas TPFM and BPFM raised it by 2.0°C and 1.8°C, respectively. On a sunny day during sprout emergence, RPM reduced the maximum soil temperature by about 5°C, while TPFM and BPFM enhanced it by about 11°C and 6.0°C, respectively. The temperature difference between the control and the mulching treatments decreased with the development of canopy. All the mulching treatments had an advantage in preserving the soil moisture over the control. RPM and BPFM resulted in the effective control of weed by obstructing light transmission onto soil surface, but TPFM had no control effect of weed. Sprout emergence started two to three days earlier in TPFM and BPFM, but one day later in RPM than in the control due to the altered soil temperature by the mulching treatments. However, the final percentage of emergence was notably lower in TPFM than that in the control because of too high soil temperature during daytime, but was not different among the control, RPM, and BPFM. During the early stage of potato growth, the shoot and root growth under RPM was lower compared with the control, but afterwards, RPM outpaced the control. In 1998 experiment, the tuber yield under RPM and BPFM were significantly higher than those of the control and TPFM. In 1999 experiment, there was no significant difference in tuber yield between RPM and the control.

Keywords **:** potato, spring season culture, yield, soil environment, mulch, recycled paper.

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Generally, potatoes are grown in spring season in Korea. For securing good yield in spring season culture, it is important to plant early and hasten sprout emergence. Therefore, polyethylene film, which is effective in raising soil temperature, has been used popularly for mulching the potato field. However, it is not always desirable to use mulching materials which are effective in raising soil temperature, since relatively low temperature is more favourable for tuberization and subsequent tuber growth of potato. Many types of mulch have long been used on many crops to modify soil temperature, conserve soil moisture, and prevent soil erosion and nutrient losses (Jensen, 1988; Adams, 1967; Anderson *et al.*, 1995). Polyethylene film mulch not only increases crop yield and achieves early harvest in many crops by raising soil temperature and preserving soil moisture, but also is easy to handle and durable (Jensen, 1988; Unger, 1978). Thereby, polyethylene film has been the most popular material for mulching. However, the polyethylene film must be removed after use and the residue contaminates soil and the surrounding environment, as it does not decompose easily. For this reason bio-degradable materials like mulch paper have been developed as alternatives to the polyethylene film (Lee *at al.*, 1997; 1998; Anderson *et al.*, 1995; Umezaki and Tsuno, 1998). Paper mulch was reported to have resulted in a suppressed weed occurrence as well as lower soil temperature than the non-mulched control in rice and summer garden plants (Anderson *et al.*, 1995; Umezaki & Tsuno 1998; Lee *et al.*, 1997; 1998). The soil temperature lowering during the early growth stage of rice through the paper mulching had no significant effects on the growth and yield (Lee *et al.*, 1997; 1998). On the other hand, the growth of summer garden plants including tomato was delayed by lowering the soil temperature through the paper-mulching treatment (Anderson *et al.*, 1995). However, the effect of RPM on spring-grown potato has not yet been addressed.

The present study was conducted to examine the effects of mulching treatments including RPM on the soil environment and the growth and yield of spring-grown potato.

MATERIALS AND METHODS

Field experiments were conducted over two spring seasons in 1998 and 1999 at the Experimental Farm (37° 16'N, 126° 59'E) of Seoul National University, Suwon, Korea. The experimental field was a loamy soil in which organic matter, CEC, and soil nitrogen were relatively low. The air temperature and rainfall during the potato growth period are shown in Fig. 1.

The mulching treatments comprised RPM, BPFM, TPFM, and the control in 1998 and RPM and the control in 1999. Polyethylene films were 0.01 mm thick and the mulch paper, 110 g/m^2 with a thickness of 0.1 mm was manufactured from recycled, corrugated containers (Dongil Paper Manufacturing, Inc.). The mulching materials were covered after planting and cut at the spots where potatoes were planted in the form of a cross (5 cm), enabling the potato sprout to emerge. The experimental plot was arranged in a randomized block design with three replications. Cultivar 'Sumi' was used for the experiments. Potatoes were cut into pieces of about 60 g each, healed the wound for several days in a cool place, and the presprouted pieces were planted. Seed potatoes were planted on 30 March at a spacing of 30 cm × 30 cm in 1998, and on 15 April at a spacing of 45 cm × 60 cm in 1999, respectively. Fertilizers of 100 kg (N), 100 kg (P), and 120 kg (K) per hectare were applied basally before planting in each year.

Sprout emergence was recorded every other day during the periods of potato emergence in 1998, and only the final sprout emergence in 1999. Shoot dry weight, root dry weight, leaf area index, and tuber fresh weight were measured from four plants sampled from each plot at interval of 7 days in 1998. Potato tuber yield were determined, excluding tubers smaller than 2 cm in diameter. In 1999, only the tuber yield was measured. Three pieces of mulch paper were cut from the mulched paper, washed with water, dried for two days in a dry oven of 80°C, and weighed in order to examine the decomposition process of mulch paper. The occurrence and dry weight of weeds were measured 40 days after planting.

Thermocouples were placed at 5 cm deep from the soil surface and average soil temperature was recorded throughout growing season at interval of 10-minutes using data logger (Campbell Inc. Model CR10, USA). Soil moisture was measured gravimetrically in 5 cm increment down to 15 cm depth at about 15 days interval.

RESULTS

Soil temperature and soil moisture

The diurnal changes of soil temperature at 5 cm depth under mulching treatments were shown in Fig. 2. They var-

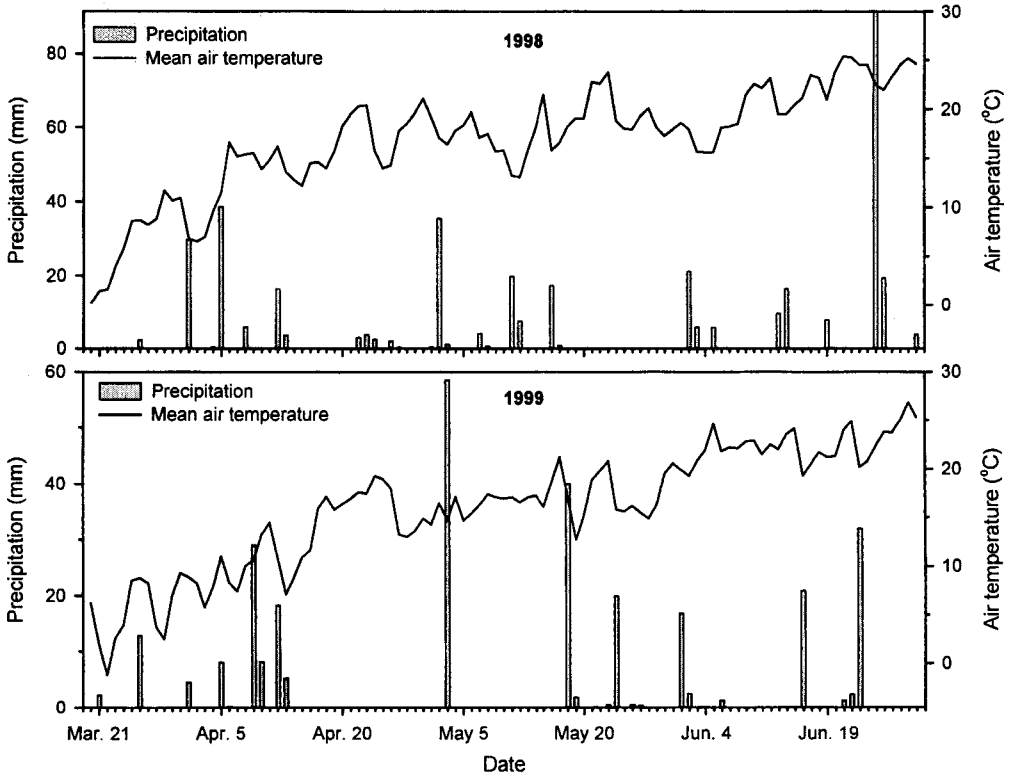

Fig. 1. Daily precipitation and mean air temperature from March 20 to June 30 at Suwon, Korea.

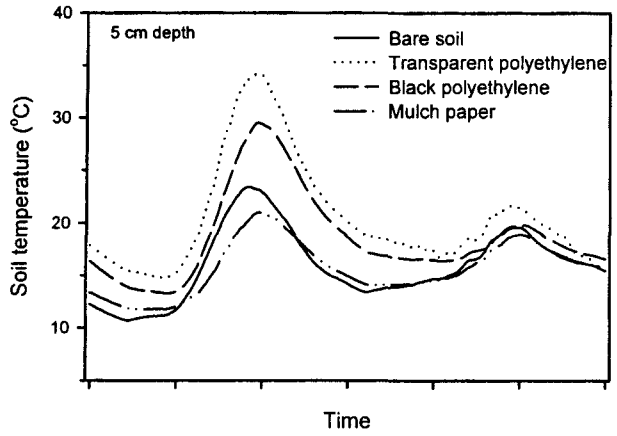

Fig. 2. Diurnal marches of soil temperature at 5 cm depth as influenced by mulching treatments on April 11 to 12, 1998 at Suwon.

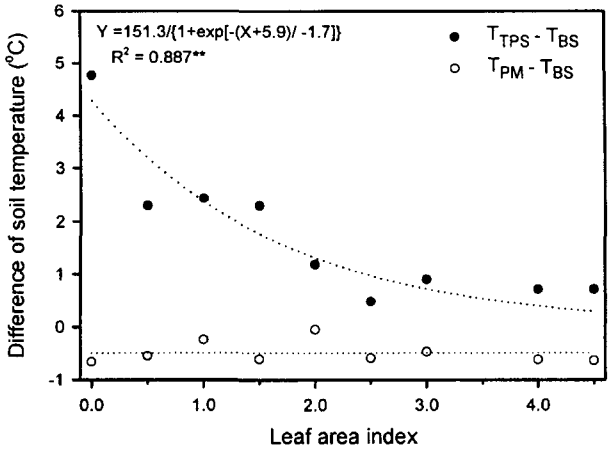

Fig. 4. Changes in daily mean soil temperature difference at 5 cm depth between non-mulching and mulching treatments in relation to leaf area expansion, Data were collected during spring season potato culture in 1998 (T_{TPS}-T_{BS} and T_{PM}-T_{BS}: the temperature differences between transparent polyethylene film mulch and bare soil and between paper mulch and bare soil, respectively).

ied greatly among the different mulching treatments and the mulching effects were different depending on the daily climatic condition. On April 11, 1998 when it was sunny and potato sprout was not emerged yet, the maximum soil temperatures during the day time were 10.7°C and 6.0°C higher under TPFM and BPFM than that under the control, respectively, whereas that under RPM was 4.9°C lower than that under the control. During the night time, soil temperature were higher in the mulching treatments, even RPM than the control. On a cloudy day (April 12, 1998), the temperature differences among the mulching treatments became much smaller compared with those of a fine day.

The seasonal changes of the daily mean soil temperature at the 5 cm depth were shown in Fig. 3. The average soil temperature during the entire potato growing season was 17.2°C under RPM, being lower 0.3°C than under the control. The soil temperatures under TPFM and BPFM were 19.5°C and 19.3°C, and were higher 2.0°C and 1.8°C than under the control, respectively. The temperature differences among the treatments were markedly big at early stage of potato growth, but tended to decrease with potato growth. As shown in Fig. 4, the temperature difference between TPFM and the control decreased exponentially with the increase of leaf area index. However, the temperature difference between RPM and the control was always small regardless of the leaf area development.

Soil moisture condition was affected markedly by mulching treatments and the weather condition (Table 1). The soil moisture contents under TPFM, BPFM, and RPM was higher than the control, while significant differences were not found among the mulched treatments. The effects of the mulching on soil moisture conservation was more conspicu-

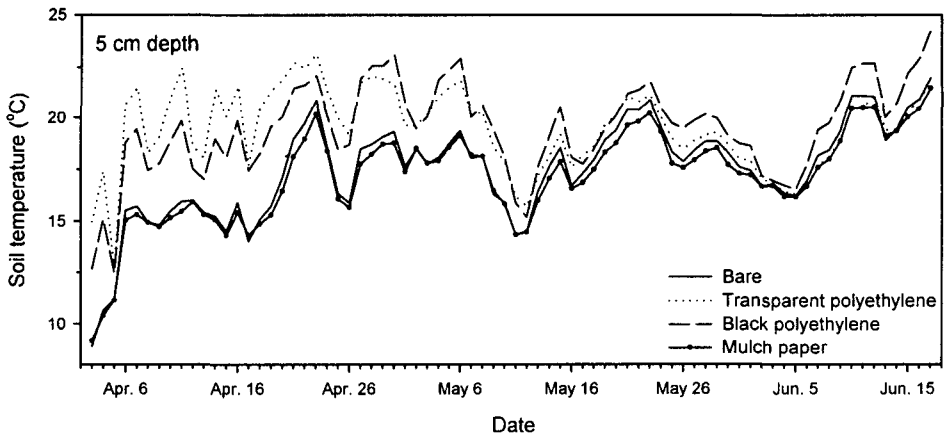

Fig. 3. Changes in daily soil temperature at 5 cm depth as influenced by mulching treatments during the period of spring season potato culture at Suwon in 1998.

Table 1. Soil moisture content as influenced by mulching treatments during spring season potato culture in 1998.

Soil depth (cm)	Mulching Treatment	Sampling date			
		April 27	May 29	June 10	June 24
		---------- % (volume) ----------			
0-5 cm	Bare	20.4[b†]	11.7[b]	18.7[a]	13.9[a]
	Transparent polyethylene	22.3[a]	19.4[a]	21.1[a]	17.5[a]
	Black polyethylene	23.7[a]	21.7[a]	20.4[a]	16.8[a]
	Mulch paper	22.6[a]	19.1[a]	20.5[a]	14.8[a]
5-10 cm	Bare	25.1[a]	16.7[b]	21.3[b]	18.4[a]
	Transparent polyethylene	25.0[a]	21.9[a]	24.6[a]	20.1[a]
	Black polyethylene	26.6[a]	24.7[a]	25.5[a]	20.0[a]
	Mulch paper	27.1[a]	22.7[a]	24.5[a]	19.6[a]
10-15 cm	Bare	27.5[a]	19.7[b]	21.8[b]	19.2[a]
	Transparent polyethylene	28.7[a]	23.7[a]	23.7[ab]	21.2[a]
	Black polyethylene	28.8[a]	24.9[a]	27.6[a]	20.8[a]
	Mulch paper	28.6[a]	24.8[a]	25.7[ab]	20.5[a]

†The same letter within the column means no significant difference by Duncan's multiple range test at 0.05 probability level.

ous during the dry period. On 29 May until when there were no rainfall for 10 days, there were significant differences in soil moistures of all the measured soil layers between the mulched treatments and the control.

Decomposition of mulching paper and occurrence of weeds

For the efficient control of weeds, mulching paper should be durable until crop canopy became developed so as to shade the soil surface. The mulch paper decomposed slowly, remaining about 80% until about 80 days after mulching (Fig. 5). Accordingly, weed occurrence was suppressed effectively in RPM until the potato harvest. A great number of weeds occurred in the control and TPFM, while no weeds occurred in BPFM and RPM (Table 2).

Potato growth and tuber yield

The temporal changes of potato emergence and the final

Table. 2. Occurrence of weeds and dry weight of weeds in potato field mulched with paper and polyethylene films in 1998 experiment.

Item	Treatment			
	Bare	Transparent polyethylene	Black polyethylene	Mulch paper
Weeds number (no./m^2)	1011	667	0	0
Dry weight (g/m^2)	341	184	0	0

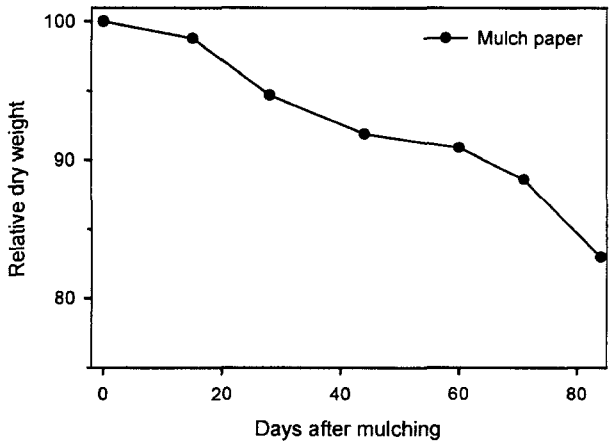

Fig. 5. Temporal degradation of mulch paper in upland field condition. Paper was mulched on March 30, 1998.

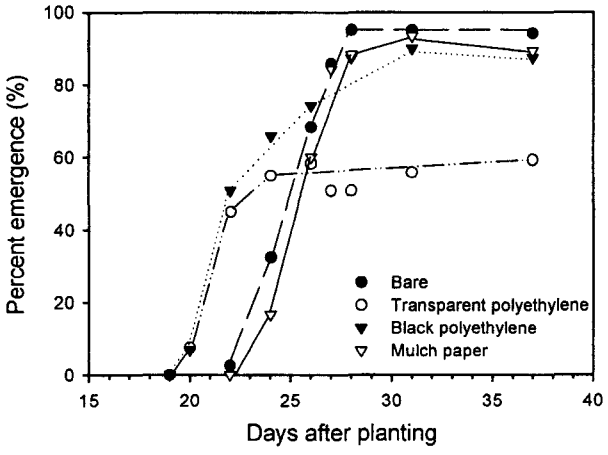

Fig. 6. Potato sprout emergence as influenced by mulching treatments in 1998 spring season culture.

Table 3. Sprout emergence in spring season potato culture as influenced by mulching treatments.

Mulch treatment	Year	
	1998	1999
	-------- % --------	
Bare	94.1[a†]	85.6
Transparent polyethylene	59.2[b]	-[‡]
Black polyethylene	87.5[a]	-
Mulch paper	93.3[a]	87.1

†The same letters within column means no significant difference by Duncan's multiple range test at 0.05 probability level.
‡The transparent and black polyethylene film was not treated in 1999.

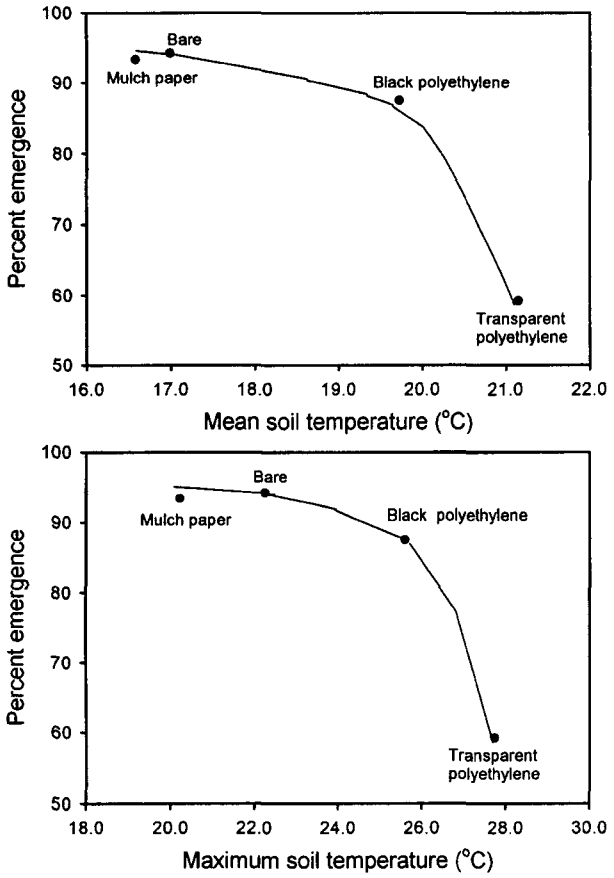

Fig. 7. The relationship between percent emergence and daily mean soil temperature (top), and daily maximum soil temperature (bottom) during emergence period in spring season potato culture in 1998.

emergence were shown in Fig. 6 and Table 3, respectively. Potato sprouts began to emerge in BPFM and TPFM at 20 days after planting, while 2 to 3 days later in the control and RPM. Potato sprout emergence started and progressed more quickly in BPFM and TPFM compared to the control, whereas it slowed down beginning 23 days after planting and thereafter showed no progress in TPFM. The final emergence was significantly lower in TPFM than the other treatments. A little delayed in the progress of emergence in RPM did not affect the final emergence. There was no differences in sprout emergence between the control and RPM in both experimental years.

Fig. 7 shows the relationships between potato emergence and the average soil temperatures at 5 cm depth during the periods of potato emergence. The potato emergence decreased with the elevation of soil temperature. At the range of 17°C-19°C in the average of daily mean soil temperature, there were no substantial differences in the potato emergence, but sprout emergence dropped sharply above 21°C. Sprout emergence showed the similar relationship to the average maximum temperature, decreasing abruptly above 26°C.

Shoot dry weight, root dry weight, leaf area index, and tuber fresh weight were measured throughout the growing season, and was shown in Fig. 8. Potato growth was the lowest in TPFM of the other treatments throughout the growing season, mainly due to low sprout emergence, and the highest in BPFM due to earlier and relatively high emergence of potato sprout. Potato growth at the early growth stage was a little poorer in RMP than that in the control, while potato growth in RPM outpaced that in the control immediately after mid May.

Significantly lower tuber fresh weight was observed in TPFM throughout the tuber bulking period. In RPM tuber bulking was delayed a little compared with those in BPFM and the control but accelerated immediately, exceeding that in the control and being similar to that in BPFM at harvest (Fig. 8).

There were significant differences in the tuber yield among the treatments in 1998 (Table 4). The tuber yields from RPM and BPFM were significantly higher than those from the control and TPFM. The lowest tuber yield was recorded in TPFM. In 1999 there were no significant differences in the tuber yield between the control and RPM.

DISCUSSION

Low soil temperature and scarcity of soil moisture are major constraints on the spring-grown potato in Korea. One of the methods to solve this problem is to mulch with plastic films. The plastic film mulching is very effective in raising soil temperature and conserving soil moisture, enhancing earlier growth and preventing frost damage (Collins, 1976). However, plastic film has been one of the major factors contributing to the contamination of agricultural environments. In the present study RPM, as an alternative to plastic film mulching, was compared with TPFM, BPFM, and the control in terms of soil temperature, soil moisture, and potato

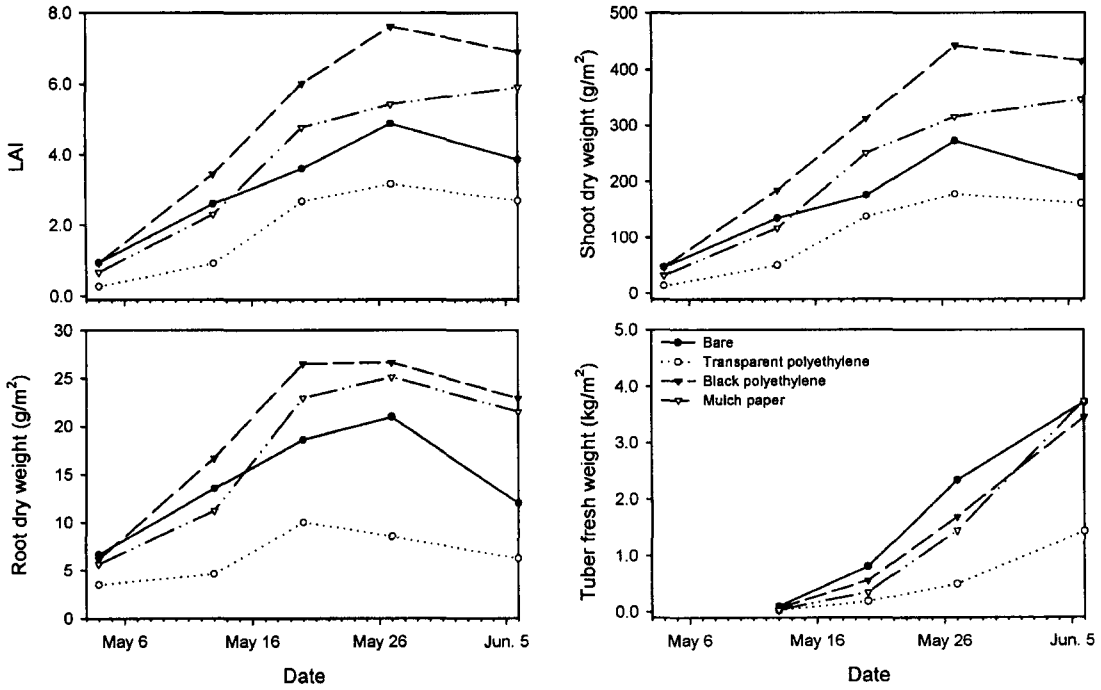

Fig. 8. Changes in leaf area index, shoot and root dry weight, and tuber fresh weight of potato as influenced by the mulching treatments in spring season potato culture in 1998.

Table 4. Fresh tuber yield in fall season potato culture as influenced by type of mulch.

Mulch treatment	Year	
	1998	1999
	-------- t/ha --------	
Bare	52.2[b*]	42.6
Transparent polyethylene	31.2[c]	-
Black polyethylene	64.8[a]	-
Mulch paper	65.7[a]	41.6

*The same letters within column means no significant difference by Duncan's multiple range test at 0.05 probability level.
†The transparent and black polyethylene film was not treated in 1999.

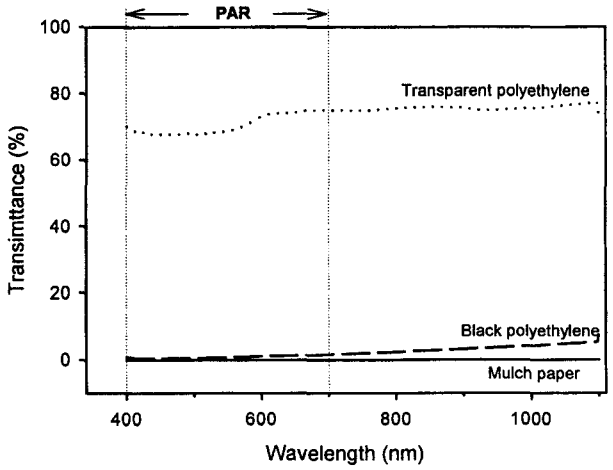

Fig. 9. Spectral transmittance of mulch materials.

growth and yield in spring season over two years.

RPM lowered the soil temperature of 5 cm depth significantly compared with the control, while BPFM and TPFM raised it substantially especially during the daytime (Fig. 2). The mulching effects on soil temperature decreased with potato growth (Fig. 3), the temperature differences decreasing exponentially as the canopy develops (Fig. 4). The mulching treatments clearly improved the soil moisture especially during dry period (Table 1). RPM showed the same effectiveness as TPFM and BPFM in the conservation of soil moisture. Besides, RPM showed very efficient weed control (Table 2) as it was durable until the full development of potato canopy (Fig. 5) and transmitted little solar radiation down to the soil surface (Fig. 9).

RPM delayed the sprout emergence a few days and the subsequent early growth as it lowered the soil temperature (Fig. 6, Fig. 8), but the final emergence was similar to the control and higher than TPFM and BPFM. In TPFM and BPFM, sprout emergence started a little earlier than the control, but the final emergence was much lower especially in TPFM because seed potato was decayed due to excessively high soil temperature (Fig. 7).

There were great differences in the shoot dry weight, root dry weight, leaf area index, and tuber fresh weight among

the treatments (Fig. 8). In RPM, the early growth was retarded a little but outpaced that in the control immediately after mid May. And tuber yield in RPM was significantly higher in 1999 and similar in 1999 compared with the control (Table 4). This may be due to the improved soil moisture and the lowered soil temperature in the later growth stage in RPM (Table 1). BPFM showed the best shoot and root growth throughout the growing season apparently due to the higher soil temperature and improved soil moisture. However, the luxurious growth in BPFM was not reflected on the tuber yield, recording no difference in tuber yield from RPM (Table 4). The overgrowth of shoot might have hampered the partitioning of photosynthate to the tuber because of the increased respiration. Growth and tuber yield were the lowest in TPFM as the sufficient plant stand could not be secured due to high soil temperature. Collins (1976) also reported that the raising of soil temperature under black and transparent polyethylene film mulching led to quicker progress of potato emergence in the low temperature region, but this effect did not affect the tuber yield.

It could be concluded that the conservation of soil moisture, suppression of weed, and lowering of daytime soil temperature through RPM contributed to the yield improvement, and the delayed emergence due to a little lower soil temperature did not led to yield reduction.

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