EFFECT OF MULCHING WITH PLASTIC FILMS ON INTENSITY OF ILLUMINATION, TEMPERATURE, MOISTURE AND *p*H OF SOIL, GROWTH OF LETTUCE AND WEED CONTROL

Yasuo KASAHARA and Katsuhisa NISHI

The use of paper mulch on a large scale in agriculture was originated in 1914 by Eckhart. He used this technique for the culture of sugar cane. Since then, numerous paper mulch experiments have been made in the United States, Canada, etc. In Hawaii, the efficiency of the mulch was so great that its use became standard plantation practice, especially in the culture of pineapple. The results obtained by many workers indicate that paper mulch affects the growth of crops and the emergence of weeds by its influence on several evironmental factors. Flint (1928) described that in addition to the biophysical modifications effected by the impervious paper mulch, the weed control as an item in the cost of crop production would have an important economic bearing on the practical utility of the mulch.

From the autumn of 1961 to the spring of 1962, we studied on the weed control by mulching with plastic films. The results obtained are reported in this paper.

MATERIALS AND METHODS

The planting beds were raised about 25 cm above the ground level in a rectangular form, $60\times240\sim255$ cm. Between two neighboring beds, narrow strip of about one foot wide was provided as a foot path. Each bed consisted of two parts. One part of the bed was covered with black "Teflon" film* (BFF), vinyl films of green (GVF), yellow (YVF) or transparency (TVF) or polyethylene film of white color (WEF), which was perforated at 15 cm interval on either side (33cm interval) of the film. Thickness of those films was as follows; BFF 0.11 mm. GVF 0.07 mm, YVF 0.13 mm, WEF 0.11 mm and TVF 0.05 mm. Lettuce seedlings were planted in the holes on October 25, 1961. The other part of the bed was used for control experiments without film. The plots thus provided were disignated as shown in Table 1 and Fig. 1. The experimental field was divided into three blocks. Each block consisted of a series of five beds provided as above. Average data of the three blocks were shown throughout this paper except in Tables 6 and 7.

The temperatures were measured (1) at the depth of 1 cm from soil surface,

* The abbreviations used are: BFF, black "Teflon", FEP-fluorocarbon film; GVF, green vinyl film; YVF, yellow vinyl film; TVF, transparent vinyl film; WEF, white polyethylene film.

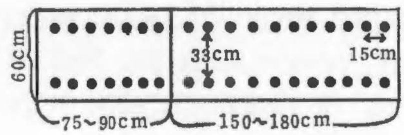


Fig. 1. Plane figure of beds. plot C consists of five plots, i. e. plots C_{BFF}, C_{GVF}, C_{YVF}, C_{TVF} and C_{WEF}.

(2) on the surface of film, (3) under the film (on the soil surface). Intensity of illumination under these films, moisture and pH of soil were also measured. For these measurements the thermistor or the ground maximum and minimum thermometer, Toshiba illuminometer, Schimadzu soil moisture meter (gypsum block electrical resistance methods) or the infrared ray moisture meter and portable glass electroad pH meter were used.

EXPERIMENTAL RESULTS

Comparisons of the numbers of weeds in 300 cm^2 at centre and edge under each mulch film are shown in Table 1 and Fig. 2. The numbers of weeds at the centre were largest in plots C and TVF, next in plots YVF, WEF and GVF and smallest in plot BFF.

TABLE 1
Effect of mulching with various plastic films on the emergence rate of annual weeds.

Plot	Color of film	Center (per 300 cm^2)				Edge (per 300 cm^2)			
		Nov. 14	Nov. 29	Dec. 18	Feb. 21	Nov. 14	Nov. 29	Dec. 18	Feb. 21
TVF	transparency	65	60	47	43	67	67	58	32
WEF	white	45	33	26	11	60	56	51	33
YVF	yellow	58	52	46	25	62	40	40	28
GVF	green	44	33	25	10	53	27	18	9
BFF	black	2	2	3	0	13	0	3	0
C	control	75	65	52	41	86	74	56	43

In early stages, the number of weeds was smaller under TVF than in plot C, but weeds grew better, throwing up the film. The circumstances under the film resembled those of tunnel cultivation with plastic film. The temperature was considerably raised. As a result, weeds under TVF grew well. In January they teared the film at places. Thereafter the temperature under the film became lower than that of plot C. At the edge of beds, similar results were obtained on the growth of weeds.

As shown in Table 2, the numbers of weeds (per 1 m^2) at the end of this ex-

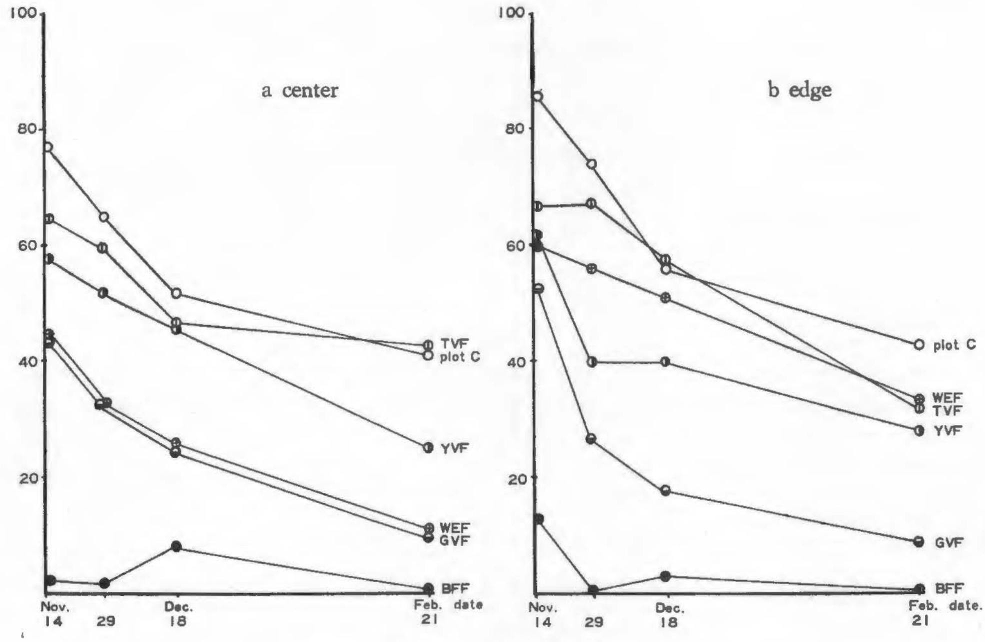


Fig. 2. Changes of number of weeds.

periment (April. 17. '62) are as follows: 825 (100%) in plot C, 419 (50.8%) in plot TVF, 147 (17.8%) in plot WEF, 138 (16.7%) in plot YVF, 40 (4.9%) in plot GVF, 3.4 (0.4) in plot BFF. There are observed 7 species (annuals) in plot C, 16 species (annuals + perennials) in plot TVF, 19 species in plot WEF, 15 species in YVF, 13 species in plot GVF and 1 species in plot BFF. The weights of weeds are as follows: 1242g (100%) in plot C, 342g (27.5%) in plot TVF, 107g (8.7%) in plot WEF, 44g (3.5%) in plot YVF, 18g (1.2%) in plot GVF, 2.7g (0.2%) in plot BVF. From these results, it is considered that mulching with BFF and GVF have advantages over hand weeding in weed control.

The majority of weed which emergenced under these films were ***Cerastium viscosum***, ***Capsella Bursa-pastoris***, ***Stellaria media***, ***Veronica persica***, ***Poa annua*** and some other annual weeds. The relation between color of films and kind of weeds were not so clear. However, ***Poa annua*** emergenced a little better under TVF than in the other cases. The number of this weed was in the following order: plot TVF, > plot C = plot YVF, > plot WEF, > plot GVF. Similarly ***Stellaria media*** was less under WEF than under YVF. ***Lamium amplexicaule*** didn't emergence under TVF and WEF but it emergenced a little under YVF and GVF (see Table 3, Fig. 3, 4).

Lettuce grew equally well under all films in early stage, but after January it grew better under BFF and TVF. And in early spring the growth of lettuce under TVF fell for the reason of luxuriant growing of weeds. On the other hand, in plot BFF where the weeds scarecely grew, lettuce showed good growth till late. As

TABLE 2

Amount of weeds under mulching with plastic films (April 17)

(per $1m^2$)

	Name of weed	TVF		WEF		YVF		GVF		C	
		Number	Weight (g)	Number	Weight (g)	Number	Weight (g)	Number	Weight (g)	Number	Weight
Annuals	*Gnaphalium multiceps* WALL.	5.8	4.4	2.1	2.7	7.3	2.3	0.3	0.03	—	—
	Erigeron linifolius WILLD.	—	—	3.0	7.1	1.2	0.6	0.3	0.03	—	—
	Erigeron sumatrensis RETZ.	—	—	0.3	0.2	—	—	—	—	—	—
	Galium Aparine L.	1.1	0.5	0.3	0.3	0.6	1.2	1.1	0.69	10.3	4.5
	Veronica persica POIR.	28.6	25.1	3.6	2.7	1.2	0.2	3.6	1.27	67.0	62.6
	Veronica arvensis L.	—	—	0.3	0.1	—	—	—	—	—	—
	Lamium amplexicaule L.	—	—	—	—	0.6	0.8	7.3	1.23	14.3	15.5
	Bothriospermum tenellum FISCH. et MEY.	8.0	4.1	1.8	1.3	2.1	1.1	—	—	—	—
	Capsella Bursa-pastoris MEDIC	51.2	44.3	22.0	17.2	45.4	3.7	1.1	1.12	332.6	789.7
	Sagina japonica OHWI	0.3	0.3	0.6	0.5	—	—	—	—	—	—
	Cerastium viscosum L.	269.0	237.5	82.8	60.9	44.7	17.2	17.1	6.39	342.5	281.4
	Stellaria media CYR.	23.2	13.5	8.4	3.5	16.6	12.7	3.6	1.09	46.3	84.4
	Stellaria Alsine GRIMM var. *undulata* OHWI	0.8	0.1	2.5	0.3	1.5	0.6	0.3	0.22	—	—
	Poa annua L.	22.9	7.6	4.5	0.5	11.8	1.5	1.4	2.91	12.0	4.2
	Total	410.8	337.4	132.2	97.2	133.0	42.0	36.2	14.98	825.0	1242.2
	Percentage for plot C	49.8	27.2	16.0	7.8	16.1	3.4	4.4	1.20	100.0	100.0
Perennials	*Plantago asiatica* L.	2.2	0.4	—	—	0.3	0.2	—	—	—	—
	Mazus Miquelii MAKINO	—	—	3.9	0.6	—	—	—	—	—	—
	Hydrocotyle maritima HONDA	0.3	0.3	4.5	4.0	—	—	0.3	0.7	—	—
	Viola mandshurica W. BECKER	0.3	0.6	—	—	—	—	—	—	—	—
	Viola japonica LANGSD.	0.3	0.4	0.9	1.3	2.7	0.2	—	—	—	—
	Trifolium repens L.	0.3	0.1	0.6	0.1	—	—	0.3	0.3	—	—
	Rorippa indica HIERN.	—	—	—	—	0.6	0.3	—	—	—	—
	Cyperus. rotundus L.	4.4	2.3	3.6	2.1	1.2	0.8	3.6	1.6	—	—
	Equisetum arvense L.	—	—	1.2	1.6	—	—	—	—	—	—
	Total	7.9	4.1	14.8	9.6	4.8	1.6	4.3	2.6	—	—
	Grand total	418.7	341.5	147.0	106.8	137.8	43.5	40.4	17.6	825.0	1242.2
	Percentage for plot C	50.8	27.5	17.8	8.7	16.7	3.5	4.9	1.2	100.0	100.0

Note: Weed in BFF is only *Equisetum arvense* L., 3.4 in number and 2.7 g in weight.

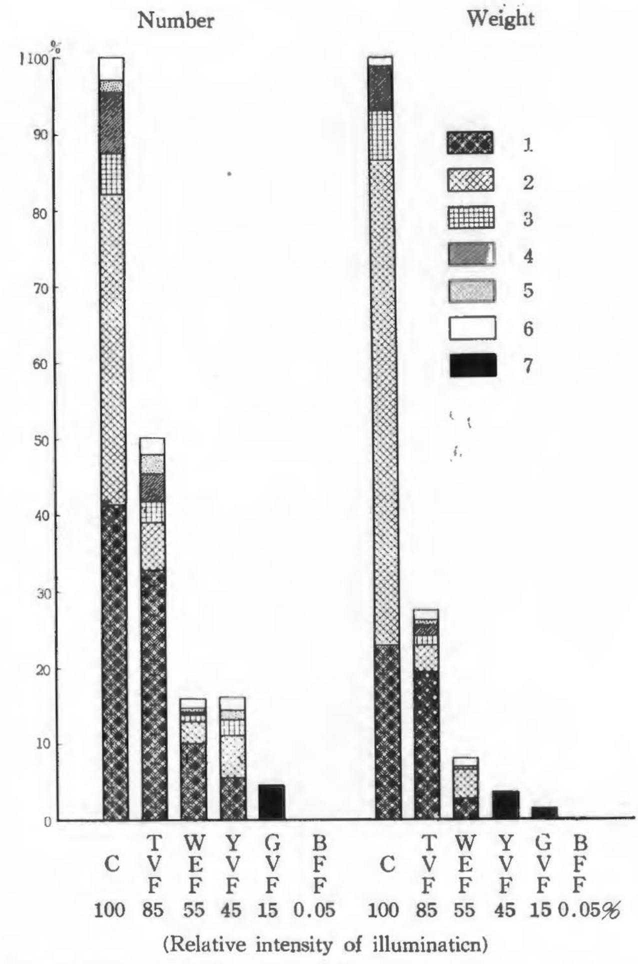


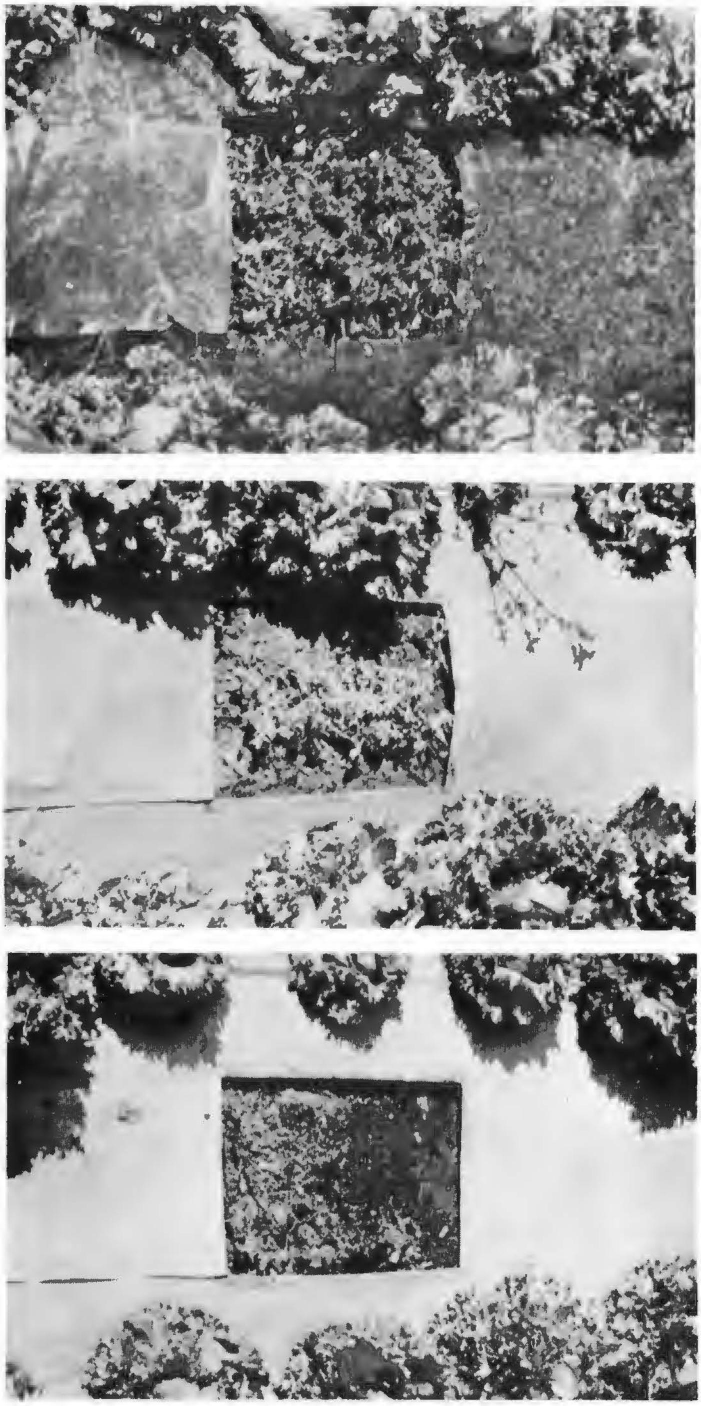
Fig. 3. Effect of mulching with various plastic films on the emergence rate of annual weeds. 1. ***Cerastium viscosum L.*** 2. ***Capsella Bursapastris*** MEDIC. 3. ***Stellaria media*** CYR. 4. ***Veronica persica*** POIR. 5. ***Poa annua,*** L. 6. Others. 7. Annual.

shown in Table 3 and Fig. 5., the yield of lettuce were equally high in plots BFF, YVF and GVF, somewhat low in plots WEF and TVF, and minimum in plot C owing to luxuriant growing of weeds.

Changes in the environment of experimental field by mulching are as follows.

(1) ***The Temperatures Measured on and under Mulch Films and at the Depth of 1 cm from Soil Surface.***

At daytime of fine day, the temperatures on BFF, TVF, YVF and WEF were higher than that of soil surface in plot C which was equal to the temperature on GVF. (Tables 4 and 5). The temperatures were; 30.0°C on BFF and TVF, 28.0°C on YVF, 27.4°C on WEF, 26.8°C on GVF and 25.4°C at soil surface in plot C. On clouded day, the temperatures on all films were approximately equal

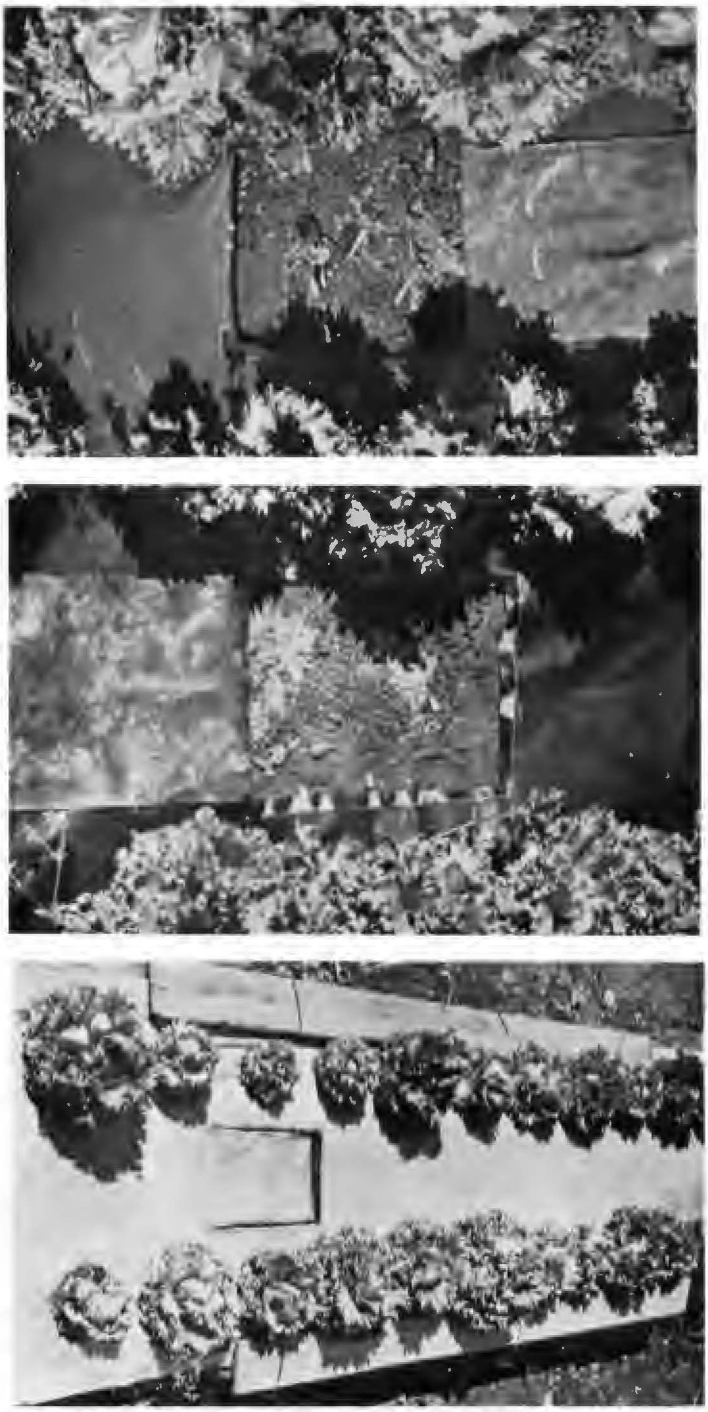


TVF

YVF

WEF

Fig. 4. a Emergence of weeds under mulch films and growing of lettuce (Photographed, April 16, 1962.)



GVF

BFF

An example of mulching

Fig. 4. b Emergence of weeds under mulch films and growing of lettuce.
(Photographed April 16, 1962.)

TABLE 3

Effect of mulching with various plastic films on yield of lettuce and amount of weeds (per 1 m²).

	Lettuce			Weeds				
	Number	Weight	Percentage per plot C	Number	Percentage per plot C	Weight	Percentage per plot C	Weight of individual
TVF	19.7	2,066g	145.4%	419	50.8%	341.4g	27.5%	0.815g
WEF	19.0	2,104	148.1	147	17.8	107.9	8.7	0.734
YVF	18.7	2,251	158.4	138	16.7	43.7	3.5	0.317
GVF	18.7	2,217	156.0	41	5.0	15.0	1.2	0.366
BFF	19.0	2,281	160.5	3	0.4	2.7	0.2	0.800
Plot C	25.0	1,421	100.0	825	100.0	1,242.6	100.0	1.506

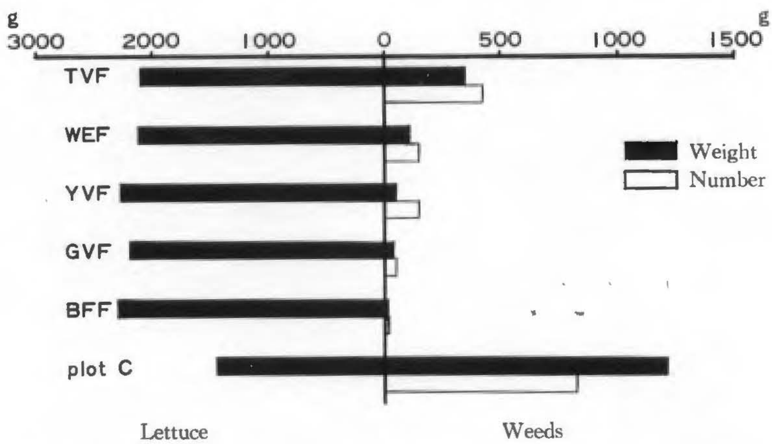


Fig. 5. Effect of mulching with various plastic films on yield of lettuce and amount of weeds (per 1m²).

TABLE 4

Temperature on and under mulch films

a, Temperature on the mulch films

Date and time / Plot	Nov. 8 a. m. 10.00 (Cloudy)	Nov. 10 a. m. 10.30 (Fine)	Nov. 29 p. m. 1.30 (Fine)	Feb. 23 p. m. 1.30 (Cloudy*)	Mar. 12 a. m. 10.00 (Fine)	Mar. 13 a. m. 10.00 (Fine)	Apr. 16 a. m. 10.00 (Fine)	Average	Fineday
C	16.8°C	25.6°C	27.3°C	22.7°C	21.1°C	25.0°C	33.0°C	24.5°C	26.4°C
TVF	20.9	23.5	31.9	21.5	32.0	28.0	33.8	27.2	29.8
WEF	19.9	21.7	27.0	19.6	—	—	33.6	24.4	27.4
YVF	19.2	22.0	29.2	22.4	29.2	27.0	32.8	26.0	28.0
GVF	20.3	23.0	28.9	17.8	28.0	26.0	28.0	24.6	26.8
BFF	20.8	28.0	28.2	28.4	31.3	29.9	32.8	28.5	30.0

* Slightly cloudy.

b, Temperature under the mulch films.

Plot \ Date and time	Nov. 8 p. m. 2.00 (Cloudy)	Nov. 10 a. m. 11.00 (Fine)	Nov. 28 p. m. 2.00 (Fine)	Feb. 23 p. m. 2.00 (Cloudy*)	Mar. 12 a. m. 10.00 (Fine)	Mar. 13 a. m. 10.00 (Fine)	Apr. 16 a. m. 10.00 (Fine)	Average	Fineday
C	16.4°C	25.6°C	27.3°C	22.7°C	21.1°C	25.0°C	33.0°C	24.4°C	26.4°C
TVF	18.0	25.1	31.8	25.8	20.8	22.9	32.7	25.3	26.7
WEF	17.2	22.6	26.0	25.3	—	—	32.2	24.7	26.8
YVF	16.6	21.4	26.1	27.5	19.0	27.5	29.0	23.9	24.6
GVF	17.3	23.5	29.9	26.2	18.2	27.1	30.2	24.6	25.8
BFF	17.7	28.0	25.8	26.1	19.0	23.8	31.0	24.5	25.5

TABLE 5

Temperature measured at the depth of 1 cm from soil surface

	Plot	Feb. 8~10	Feb. 11~20	Feb. 21~28	Mar. 1~10	Mar. 11~20	Mar. 21~27	Average
Max. temp.	TVF	14.73	11.70	13.25	14.71	18.99	17.35	15.12
	WEF	22.56	17.58	21.56	25.98	27.66	26.93	23.71
	YVF	14.80	12.74	14.98	17.10	21.86	20.68	17.03
	GVF	15.40	13.62	16.45	19.47	23.62	22.70	18.54
	BFF	11.10	8.07	8.41	9.74	12.45	10.98	10.13
Min. temp.	TVF	4.50	3.77	4.45	5.02	7.66	6.62	5.34
	WEF	1.93	−0.06	0.15	0.49	3.55	2.10	1.36
	YVF	3.07	2.20	2.88	3.28	6.09	4.62	3.69
	GVF	2.87	2.04	2.46	2.56	5.23	3.82	3.16
	BFF	3.17	2.74	3.21	3.73	6.21	5.28	4.06
Temp. at 10 a. m.	TVF	5.93	6.28	7.34	8.37	11.31	10.62	8.31
	WEF	6.33	10.62	13.11	14.67	18.04	16.38	13.19
	TVF	4.80	6.46	7.81	9.00	12.72	12.06	8.81
	GVF	4.93	6.53	8.96	10.72	14.65	13.56	9.89
	BFF	4.47	4.16	4.90	5.73	8.91	8.46	6.11
Mean of max. and min temp.	TVF	9.73	7.76	8.89	9.89	13.35	12.10	10.29
	WEF	12.27	8.80	10.68	13.24	16.25	14.60	12.64
	YVF	8.93	7.50	8.86	10.23	13.66	12.73	10.32
	GVF	9.13	7.88	9.46	11.09	14.45	13.35	10.89
	BFF	7.40	5.74	5.85	6.77	9.40	8.25	6.24

to that of soil surface in plot C. The temperature under TVF was higher than the others in early stages, but it fell in the latter half owing to the partial tearing of film by the dense growing of weeds. There was observed no trend in the other cases.

The temperatures (maximum temperature, minimum temperature, mean of maximum and minimum temperatures, temperature at 10 a. m.) of beds at the depth of 1 cm from soil surface were shown in Table 5 and Figs. 6, 7, 8 and 9. The maximum temperature was found to be in the following descending order:

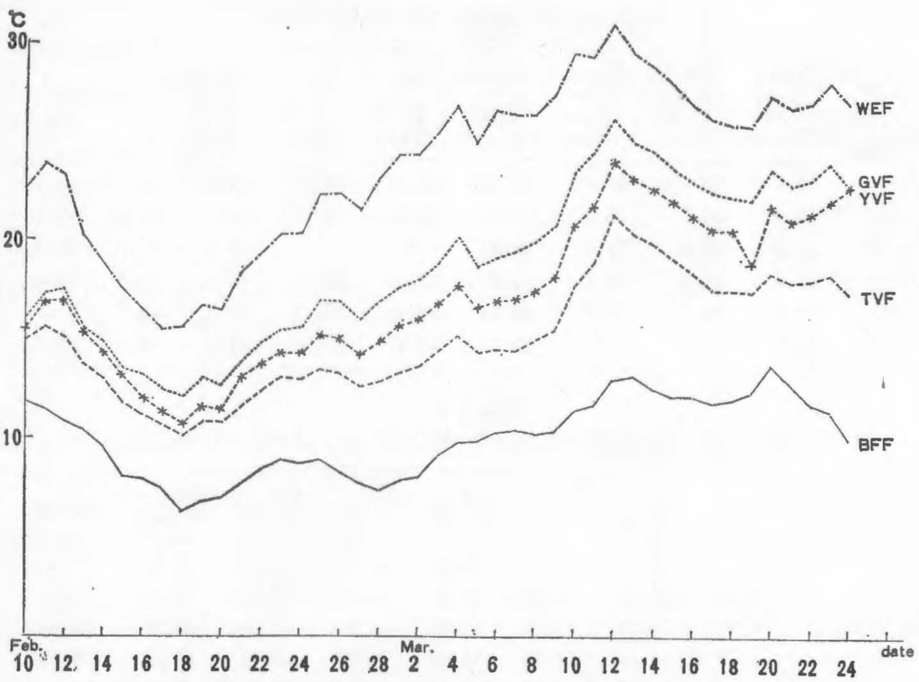


Fig. 6. Maximum temperature at the depth of 1 cm from soil surface. (Moving average of 5 days)

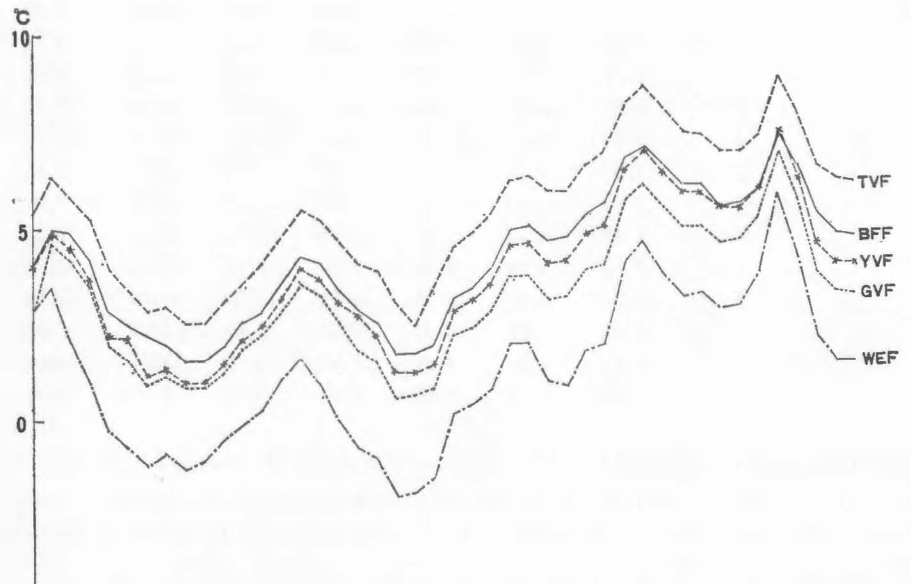


Fig 7. Minimum temperature at the depth of 1 cm from soil surface. (Moving average of 5 days)

Fig. 8. Mean of maximum and minimum temperature at the depth of 1 cm from soil surface. (Moving average of 5 days)

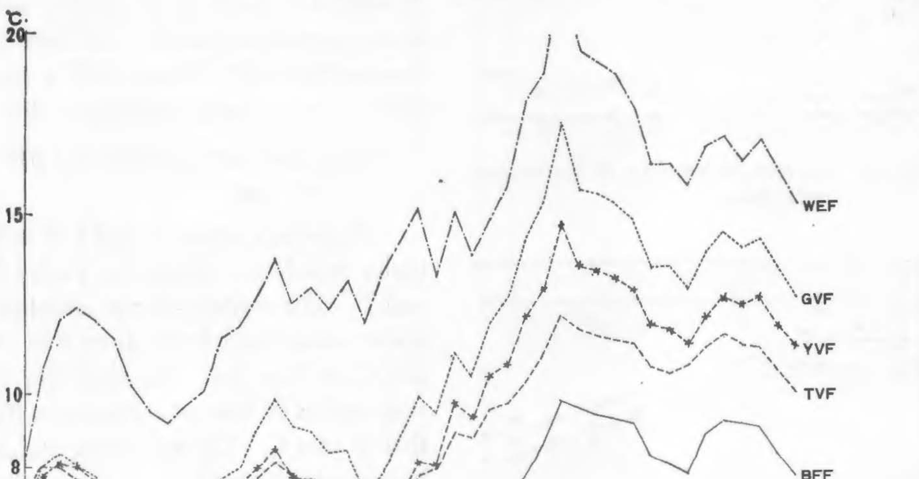


Fig. 9. Temperature at 10 a. m. at the depth of 1 cm from soil surface. (Moving average of 5 days)

WEF (average, 23.7°C), GVF (18.5°C), YVF (17.0°C), TVF (15.1°C), BFF (10.1°C).

The descending order of minimum temperature was as follows: TVF (average 5.3°C), BFF (4.1°C), YVF (3.7°C), GVF (3.2°C), WEF (1.4°C). Accordingly the ranges of temperature were 22.3°C under WEF, 15.3°C under GVF, 13.4°C under YVF, 9°C under TVF and 6.1°C under BFF. The mean values of maximum and minimum temperatures were 12.6°C under WEF, 10.9°C under GVF, 10.3°C under GVF and TVF, and 6.2°C under BFF. The temperature at 10. a.m. showed a similar tendency.

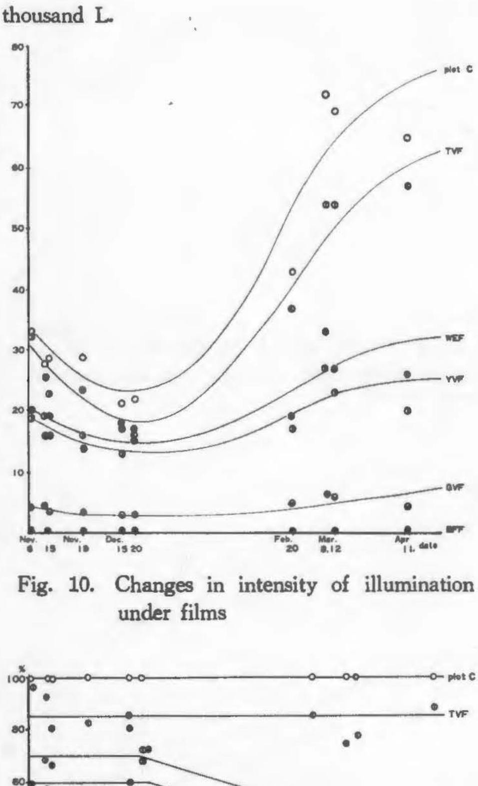


Fig. 10. Changes in intensity of illumination under films

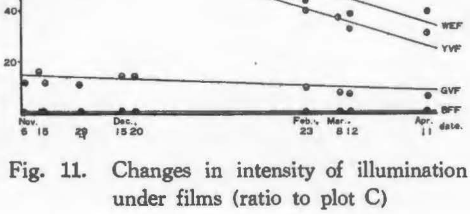


Fig. 11. Changes in intensity of illumination under films (ratio to plot C)

(2) *Intensity of Illumination*

The intensity of illumination measured at 1.30 p.m. on fine day was shown in Figs. 10 and 11. In plot C it was 33,000 Lux at the begining of November, minimum at the end of December and 70,000 Lux at the bigining of April. The intensity of illumination under TVF, changed in proportion to that of plot C; the percentage of the former to the latter being 85. Under YVF and WEF it was 60—70 % of that of plot C in the former half of experimental period, but later it became 30—40%. Under GVF it was 15%. It was nearly dark under BFF.

(3) *Moisture content and pH of Soil*

Moisture content and pH of soil under mulch are shown in Tables 6 and 7. The content of soil moisture under mulch was lower than that of plot C on fine day. On rainy day it was similar or low as compared with that of plot C. The soil under mulch became slightly acid.

TABLE 6
Moisture content of soil under films

Block	Plot	Oct. 24	Oct. 25	Nov. 8	Nov. 14	Nov. 15	Nov. 22	Dec. 7	Dec. 20	Feb. 9	Aver.
I	TVF	29.7%	—	28.0%	27.5%	27.4%	27.8%	27.2%	26.4%	26.3%	27.5%
	WEF	30.7	—	26.4	26.3	26.2	26.7	25.9	25.1	25.0	26.5
	YVF	31.6	—	26.7	26.0	26.1	26.6	26.3	25.3	25.7	26.8
	GVF	28.2	—	25.9	25.8	25.5	26.7	27.0	25.3	25.4	26.2
	BFF	29.2	—	26.6	25.4	26.1	26.6	26.8	26.5	25.0	26.5
II	TVF	31.6	31.6%	26.6	26.8	27.5	28.4	28.1	26.5	26.6	28.2
	WEF	26.3	27.4	26.9	26.4	26.0	27.0	26.7	26.3	25.6	26.5
	YVF	28.2	28.9	25.8	25.3	25.0	25.4	26.0	25.7	24.5	26.1
	GVF	31.6	32.5	27.7	28.9	28.4	29.5	28.7	27.2	26.2	29.0
	BFF	27.1	28.2	25.9	25.6	24.9	25.1	26.3	24.5	23.5	25.3
	Control	—	—	25.4	—	19.8	25.3	23.2	23.3	23.4	23.4

TABLE 7
*p*H of soil under films

Plot \ Block	*p*H Under films I	II	III	Plot \ Block	*p*H Control I	II	III
TVF	6.10	6.50	6.87	CTVF	6.18	6.57	6.89
WEF	6.18	7.02	6.32	CWEF	6.62	7.20	6.60
YVF	6.50	6.78	6.90	CYVF	6.18	7.03	7.10
GVF	6.30	6.60	6.58	CGVF	6.62	6.72	6.60
BEF	6.20	6.72	6.40	CBFF	6.85	6.88	6.80

DISCUSSION

Many attempts have been made to control weeds by the use of straw, rice hulls, hay, manure and compost. In home garden, these methods have been commonly used but they are unsatisfactory and impracticiable as weed-control measures. In our laboratory, experiments were carried out on the mulching in 1948. At that time straw, hay, compost mixed with calcium cyanamide, and green grass were used as materials of mulches. It was observed that mulchings reduced the number of weeds by half or 80% except green grass mulching.

The weed control with paper mulch economically began in the unirrigated sugar cane plantations in Hawaii by Eckart in 1914. In 1916, he extended the effectiveness of the paper mulch through the introduction of light-weight paper, impervious to water, which was laid directly over the harvested stubble or seed-cane. The sharp young shoots of cane pierced readly this mulch, while the weed growth was kept down. As the paper mulch experiment with pineapples in Hawaii gave good results, the United States Department of Agriculture initiated in 1924 a series of paper-mulch trials with various crops.

The primary utility of the mulch has been thought to be the conservation of soil moisture. According to Flint (1928), the mulched areas are characterized by more vigorous crop plants than unmulched areas kept equally free from weeds. Eckart (1923) attributed this beneficial influence to increased soil temperature and soil moisture. Larsen (1917) also considered the increased soil temperature as the most important characteristic of the mulched area.

In vegetable production, mulch paper seemed to be most advantageous for warm-season crops (Hutchins 1933). It also appeared to be most beneficial under the conditions that were unfavorable to the optimum development of the crop such as poor soil, deficient precipitation, and low temperature. Under favorable growing conditions, often very little and sometimes detrimental effects were produced. There was a decided preponderance in the number of benefical results obtained on the paper. However, the increases in many of these crops were not sufficient to pay for the additional expense.

Recent review by Crafts and Robbins (1962), have described that sheet plastic materials are now available for soil mulching and weed control. These are available in various weights, and they are usually black, hence impervious to light. Paper- or plastic-mulched soil, as compared with cultivated soil, usually has more moisture and shows a higher daily mean temperature, but there is no consistent difference in the nitrate content of the soil. Therefore it has special merit in the culture of early, quick-maturing crop, especially in periods of moisture deficiency. There were some reports of the use of black polyethylene sheet as mulch for strawberries. According to Porter (1962) black polythene mulches control annual weeds well but their effects are little on perennial weeds, such as ***Oxalis*** sp. or ***Agropyron repens***. Wandas and Svensson (1962) described that first-season yields of strawberry grown on plastic-covered ridges averaged 12,150kg per hectare and those of non-mulched crops were 7,300 kg per hectare. Mulched plants ripened slightly earlier and the incidence of moulds on the fruit was less. Bargioni (1962), after 2-year experiment with strawberry planted through holes in strips of black polythene sheeting, reported that the fruit in mulched plots ripened slightly earlier and the first-year yield was higher than that from unmulched plots. In the second year, however, yields were not increased by the mulch, and in the wider spaced plots somewhat decreased.

In Japan, several investigaters reported that the growing of strawberries were accerelated and their yield were increased by mulchings with vinyl and polyethylene films. For instance Ninomiya and Suzuki (1958) obtained the result that ripenning of strawberry was accerelated and yield of the first harvest time was increased 20—30 % by mulching with transparent vinyl film. They considered that a factor contributing these favorable results was ground temperature raised by mulching. For instance it was higher by 2—3°C on clouded days and by 2°C in morning, by 6—7°C in day-time and by 3—4°C in night on clear days than under unmulched soil surface. According to Isawa (1958), mulchings with vinyl or polyethylene film (transparent or semitransparent) in the culture of strawverry increased the temperature at the depth of 5 cm from soil surface by 4—6°C in daytime and by 2—3°C in night. It accerelated the development of root group, and hastened harvest time by 7—10 days and increased yield by 20—28 %. Mulching begun just after planting of strawberry in November showed an unsatisfactory results owing to the luxuriant growing of weeds even in winter and the competition for water and nutrients. But in mulching begun in February, the weeds growing under mulch didn't affect the growth and yield of strawberry, and the weeds prevented the injury of high temperature to the development of roots.

In Japan the practice of mulching for strawberry is not so common as tunnel or home culture with plastic films. This is perhaps caused from slight quick-ripenning, and little weeding effect of transparent film and large expene of its annual renewal. When black film is used in place of transparent one, soil temperature is lower and harvest delayed a little. Neverthless, black film has an advantage in that weeds scarcely emerge. For this reason, the cost of production might be brought down below that of tunnel culture (Isawa 1963).

Germination and growth of weed under mulch is effectcd by various factors, e. g. intensity of illumination, quality of light transmitted by the film, temperature, moisture ane pH of soil, and nutrients. So far as we are aware, no detailed surveies of intensity of illumination under mulch have been reported. Its reduction by mulching varied with the colors of film, as was to be expected. The percentage of light transmitted by TVF was found to be 90 % in visible region. That of WEF was 8—14%. By BFF the light was completely absorved in visibble region. In case of YVF and GVF the characteristic absorptions were observed. Especially under GVF the greater part of the light in the range of 550—800 mμ wave length which is essential for the growth of higher plants was absorbed. The intensity of illumination decreased with the season under WEF and TVF. The reason for this was not clarified in this study.

The temperature measured on mulch films was found to be in the following order: BFF = TVF > YVF > WEF > GVF. The order of temperature under mulch films was, WEF = TVF > GVF = BEF > YVF. The order of maximum temperature, mean of maximum and minimum temperature, at 10 a. m. at the depth of 1 cm from soil surface were as follows: WEF > GVF > YVF > TVF > BFF. As to the minimum temperature, the order was, TVF > BFF > YVF > GVF > WEF. This is the reverse of the order of temperature on mulch films except for GVF. It seems that the more heat of sun is absorbed by film, the less it reaches to the ground. According to Smith (1931), black paper raises the soil temperatures, gray paper lowers them. Shaw (1926) stated that the temperature range of soil from maximum to minimum became narrow by mulching. The average daily range of covered plot was 8.58°F and that of bare plot was 11.7°F.

According to Smith (1931) the difference of soil moisture by mulching was observed within depth of 4 inches. According to Flint (1928) the property of preserving soil moisture is not affected by paper mulching under 4 inches from soil surface. The soil moisture under mulch films was scarecely influenced by rain and the order of soil moisture content before mulching was maintained during the experiment. So far as we are aware, the issue about change of soil pH by mulching has not been reported. In this study, the pH of soil was found be slightly lowered by mulching.

The differences in the growth of lettuce among mulched plots arose in January. Lettuce of plots BFF and TVF grew better than the others. This is probably due to high temperature over the films. However, in early spring the growth of lettuce in plot TVF fell because of the luxuriant growth of weeds. The lettuce of plot BFF is the best in growth and yield. This is presumably due to less weeds and higher temperatures on the film and under the ground. Although the conditions in plot TVF was the same as those of plot BFF, the growing of lettuce in plot TVF fell in later stage and the yield decreased on account of much weed. The weeds were the least in plot BFF where the intensity of illumination under film was the least. The percentage of the intensity of illumination to that of plot C was found to be in the following order: BFF(0.05%) < GVF(15%) < YVF(45%) < WEF(55%) < (TVF(85%).

The mumber and weight of weeds seem to be proportianal to the intensity of illumination. Very close corelations were observed between the number or the weight of winter annual weeds and relative intensity of illumination. But some perennial weeds were more resistant to mulching than annual weeds.

In conclusion GVF were effective in inhibiting the germination and growth of weeds. Especially black film was considerable effective. Polyethylene film was cheap as compared with vinyl film. Teflon film has durability and bear twice use.

SUMMARY

From October of 1961 to April of 1962, we made experiments on mulching using "Teflon" FEP-fluorocabon film, vinyl films and polyethylene film as its materials.

1) The reduction in intensity of illumination under films varied with the color of films.

2) The temperatures at the depth of 1 cm from soil surface, i. e. maximum temperature, mean of maximum and minimum temperature, temperature at 10 a. m. got lowered in the order, WEF, GVF, YVF, TVF, BFF. As to the minimum temperature the descending order was found to be, TVF, BFF, YVF, GVF, WEF.

3) The differences in lettuce growing were scarecely observed in early stage. However, from the beginning of January, the lettuce in plots BFF and TVF grew better. In early spring, growing of the lettuce in plot TVF fell for the luxuriant growth of weeds, but the lettuce of plot BFF showed a good growth till late. The yields of lettuce were equally high in plots BFF, YVF and GVF, somewhat low in plots WEF and TVF and minimum in plot C owing to luxurtant growth of weeds.

4) The numbers of weeds decreased with the season except that of plot TVF. The majority of the weeds under mulches were ***Cerastium viscosum. Capsella Bursa-pastoris*** and the rest were annuals such as ***Stellaria media, Veronica persica, Poa annua.*** and some perennials. The ascending order of the number of weeds at the harvest time was BFF (the percentage to that of plot C, 0.4), GVF (5.0), YVF (16.7), WEF (17.8), TVF (50.8). As to the weight of weeds, the order was the same as the above; BFF (0.2), GVF (1.2), YVF (3.5), WEF (8.7), TVF (27.5). Close correlation existed between number of weeds, especially winter annual weeds, and relative intensity of illumination. In the cases of YVF and GVF the effect of weed control seems to be caused not only by the reduction in intensity of illumination but also by the fact that these films absorb the light in the range of wave length from 550 to 800 mμ which is important for the growth of plants.

5) In conclusion, mulching with black film inhibits germination and growth of weeds completely, accerelates the growth of plant and increases the yield. Green film has enough effect of weed control and the yield of lettuce was nearly equal to that of the plot covered with black film. Polyethylene film is cheaper than vinyl film and seems to be practical. Teflon film is durable and bears repeated use.

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