EFFECT OF MULCH ON THE SOIL MICROENVIRONMENT, YIELD OF PEPPER (*Capsicum annuum* L.), AND APHID POPULATION

by

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ABSTRACT

M.Sc. Fahrurrozi Aziz Plant Science

Effect of mulch on the soil microenvironment, yield of bell pepper (*Capsicum annuum* L.) and aphid population

Two independent experiments were conducted during 1992 and 1993 using a Randomized Complete Block Design with four replications. The first experiment was designed to study the effect of mulch spectral properties on weed growth and development. The second was conducted to study the effect of polyethylene mulch on aphid population and on growth and yield of bell pepper. Initially, rye-grass germination under polyethylene mulches was significantly higher than that on bare soil, whereas mustard seed germination under mulches did not differ significantly from that on bare soil. However, at the end of 30 days, none of these weeds were observed in the mulched plots. Transmittance, reflectance, and absorbance were recorded in the Near Ultraviolet (390 - 399 nanometre), Photosynthetically Active Radiation (400 - 700 nanometre), and Near Infrared (701 - 1100 nanometre) bands for black, black microperforated, wavelength selective and silver mulches. Aging had little effect on the optical properties of the mulches. The wavelength selective (Infra red transmitting=IRT-76) green mulch had the warmest mean soil temperatures, followed by silver, black, microperforated black mulch, and bare soil. The soil moisture content was higher under plastic mulches than in bare soil. The use of mulches significantly increased both the early and total marketable yields of pepper. Plants grown with polyethylene mulch had significantly lower number of aphids on them than did their bare soil counterparts.

RESUME

M.Sc. Fahrurrozi Aziz Phytotechnie

Effet d'un Paillis sur le Microenvironnement Edaphique, la Récolte de Poivrons (*Capsicum annuum* L.) et la Population de Pucerons

Deux expériences indépendantes ont été conduites en 1992-1993, utilisant un plan en blocs aléatoires complets avec quatre répétitions. La première expérience visait à étudier l'effet des propriétés spectrales de différents paillis sur le développement et la croissance de mauvaises herbes. La deuxième a été réalisée pour étudier l'effet de paillis de polyéthylène sur une population de pucerons et sur la croissance et la récolte de poivrons. Initialement, la germination d'ivraie sous un paillis de polyéthylène était significativement supérieure à celle observée sur un sol nu, tandis que la germination de graines de moutarde sous paillis n'était pas significativement différentes de celle obtenue sur sol nu. Cependant, après 30 jours, aucune de ces mauvaises herbes n'étaient observées dans les parcelles paillées. Les facteurs de transmission, les facteurs de réflexion et l'absorbance de radiations proches ultraviolettes (390-399 nanomètres), photosynthétiques (400-700 nanomètres) et proches infrarouges (701-1100 nanomètres) ont été mesurés pour le paillis noir, le paillis noir microperforé, le paillis à transmission sélective et le paillis argent. Le vieillissement n'a eu que peu d'effet sur les propriétés optiques du paillis. Le paillis vert à transmission sélective (transmettant les infrarouges=IRT-76) est le traitement ayant obtenu la température moyenne du sol la plus élevée, suivi du paillis argent, du paillis noir, du paillis noir microperforé et du sol nu. La teneur en humidité du sol sous paillis plastiques était supérieure à celle du sol nu. L'utilisation de paillis a augmenté significativement la récolte hâtive et la récolte totale de poivrons. Les plants cultivés sur paillis de polyéthylène ont été infestés par un nombre significativement inférieur de pucerons que ceux cultivés sur sol nu.

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Treatments	Total fruit: Marketable Number (per/plot) 1992	Marketable Number (per/plot) 1993	Marketable Weight (kg/plot) 1992	Marketable Weight (kg/plot) 1993	Cull Number (per/plot) 1992	Cull Number (per/plot) 1993	Cull Weight (kg/plot) 1992	Cull Weight (kg/plot) 1993	Harvest Index (per/plant basis) 1992	Harvest Index (per/plant basis) 1993
1. Bare soil	58.2a	30.0a	9.8a	3.9a	72.2a	26.0a	7.5a	2.5a	0.72a	0.66a
2. Black mulch	76.8b	79.0b	14.0b	12.4b	69.7a	35.5a	8.5ab	4.5b	0.75b	0.72a
3. Silver mulch-1	72.3b	79.5b	12.7b	12.3b	87.3a	42.3a	10.1c	4.4b	0.75b	0.70a
4. Silver mulch-2	74.8b	80.8b	13.4b	13.0b	76.5a	40.3a	9.5bc	4.5b	0.74b	0.72a

Notes : - Values in the same column followed by the same letter are not significantly different according to Least Significantly Different test at ($p < 0.05$).

Table 2. Spectral properties (transmittance, reflectance, and absorbance) of new polyethylene mulch materials.

Type of mulch	Transmitted light NUV	Transmitted light PAR	Transmitted light NIR	Reflected light NUV	Reflected light PAR	Reflected light NIR	Absorbed light NUV	Absorbed light PAR	Absorbed light NIR
	---% incident of radiation---								
1992:									
1. Black	0.36	0.05	0.20	5.14	5.12	4.99	94.49	94.82	94.81
2. Black micro-perforated	0.44	0.02	0.21	4.11	5.16	5.00	95.45	94.80	94.78
3. IRT-76 green	10.73	16.24	65.47	5.74	6.56	18.24	83.53	77.21	16.29
4. Silver	42.74	39.28	37.28	32.55	30.17	26.92	24.72	30.55	35.80
1993:									
1. Black	-0.36	0.79	3.20	4.93	5.17	4.99	95.44	94.04	91.78
2. Black micro-perforated	-0.28	0.01	0.04	3.70	4.94	4.82	95.44	95.05	95.14
3. IRT-76 green	9.96	14.46	64.82	5.50	6.11	17.46	84.55	79.44	17.71
4. Silver	42.77	39.73	37.44	31.14	28.60	26.09	26.09	31.66	36.47

Note: - NUV = 390 - 399 nanomatre. PAR = 400 - 700 nanometre, NIR = 701 - 1100 nanometre.

Table 3. Spectral properties (transmittance, reflectance, and absorbance) of aged polyethylene mulch materials.

Type of mulch	Transmitted light NUV	Transmitted light PAR	Transmitted light NIR	Reflected light NUV	Reflected light PAR	Reflected light NIR	Absorbed light NUV	Absorbed light PAR	Absorbed light NIR
	% incident of radiation								
1992:									
1. Black	0.05ns	0.02ns	0.08ns	5.30ns	5.04ns	5.19ns	94.65ns	94.95ns	94.73ns
2. Black micro perforated	0.13ns	0.03ns	0.04ns	4.79ns	4.88ns	4.71ns	95.08ns	95.09ns	95.25*
3. IRT-76 green	10.33ns	15.28ns	63.43**	6.03ns	6.06ns	17.66ns	83.64ns	78.66*	20.03**
4. Silver	43.07ns	40.65ns	38.36ns	30.85ns	28.75ns	26.06ns	26.09ns	30.60ns	35.59ns
1993:									
1. Black	0.74ns	0.75ns	2.91ns	5.00ns	5.03ns	4.67ns	94.26ns	94.22ns	92.43*
2. Black micro perforated	-0.04ns	-0.002ns	0.01ns	5.33ns	5.13ns	4.95ns	94.75ns	94.87ns	95.05ns
3. IRT-76 green	8.04ns	14.19ns	63.11**	5.40ns	6.08ns	16.66ns	86.56ns	79.73ns	20.23***
4. Silver	41.77ns	40.37ns	37.94ns	28.88*	28.61ns	25.94ns	29.68ns	31.02ns	36.12ns

Note: - NUV = 390 - 399 nanomatre, PAR = 400 - 700 nanometre, NIR = 701 - 1100 nanometre.
- ns, *, **, *** = nonsignificant, significant at 95 %, 99 %, and 99.9 %, respectively, according to Least Significantly Different at ($p < 0.05$) compared with the new material (Table 2).

I. INTRODUCTION

Bell pepper (*Capsicum annuum L.*), the most common type of pepper grown in Canada and USA, comprises two-third of total pepper production (Nonnecke 1989; Sundstorm, 1992). However, Quebec production is limited both by the short growing season, e.g. 157 days in the region of Montreal (Environment Canada, 1987) which does not allow the crop to reach full maturity (Hopper, 1987) and low spring temperature which inhibits the plant development (Wells and Loy, 1981).

The use of polyethylene plastic mulches to modify the growing environment has become a standard practice in commercial vegetable production in temperate climates (Sundstorm, 1992). It has been well documented that plastic mulch can increase the soil temperature (Couter and Oekber, 1964), reduce nutrient leaching (Locascio et al., 1985), conserve soil moisture (Lippert et al., 1964), and suppress weed growth (Carter and Johnson, 1988). These protective capabilities have often been considered the most important characteristics when choosing mulch. Recently, Decoteau et al. (1986, 1988, 1989), indicated that the surface colour of a mulch can alter both the quantity and quality of light reaching the plant environment, and this in turn affects plant growth and development, soil temperatures, and insect behaviour. Mulch optical properties may now be considered as important characteristic in mulch choice.

The objectives of these studies undertaken in 1992 and 1993 were :

- to study the influence of mulch spectral properties and colour on weed growth and development, soil temperatures, and soil moisture content.
- to determine the effect of aging on mulch spectral properties

- to evaluate the effect of mulch colour on pepper growth and yield
- to evaluate the influence of mulch colour on aphid population on pepper.

II. LITERATURE REVIEW

2.1. Plastic mulch application
2.1.1. Effect on soil temperatures

Plastic mulch modifies the microclimate, by effecting soil temperatures and producing a greenhouse effect (Waggoner et al., 1960; Tanner, 1974). Rosenberg et al. (1983), suggested that changing the soil temperature was probably of the greatest importance for vegetable crops grown during the spring season in temperate and cool climates. Mahrer et al. (1979), stated that " polyethylene reduces heat convection and water evaporation from the soil to the atmosphere. As a result of the formation of water droplets on the inner surface of the polyethylene, its transmissivity to long-wave radiation is highly reduced, while its transmissivity to short-wave radiation is almost unaffected, resulting in more heating due to greenhouse effect ".

In general, plastic mulches have increased diurnal soil temperatures. The increase has been influenced by mulch colour, clear polyethylene elevating soil temperature by 3 - 12 ^{o} Celsius (Schales and Sheldrake, 1966; Chen and Katan, 1980; Maurya and Lal, 1981), and black polyethylene mulch raising the soil temperature by 1.7 - 2.8 ^{o} Celsius (Schales and Sheldrake, 1966).

Maurya and Lal (1981), indicated that the effects of plastic mulch on soil temperature depended on the climate, mode of mulch application, quality and quantity of mulch material, and its rate of decomposition. The increased soil temperature, therefore, will positively affect the growth and yield of most crops. Generally, warm-season crops are more responsive to the soil-warming mulches applied early in the season than are cool-season crops (Magruder, 1930; Hill et al., 1982).

2.1.2. Effect on soil moisture

Soil moisture under the polyethylene mulches has been found by a number of researchers to be higher than that of bare soil (Takatori et al. 1964; Hopen, 1965; Maurya and Lal 1981; Mahrer et al. 1984; Patel et al., 1990). This increase may in part be due to a reduction in evaporation (Waggoner et al., 1960; Oebker and Hopen, 1974). Knavel and Mohr (1967), found that after four weeks of mulching, soil moisture under the black polyethylene mulch was higher compared to clear polyethylene mulch. They suggested that the high soil temperatures underneath the clear polyethylene, which caused a high evapotranspiration rate lowered the soil moisture level. Similarly, Emmert (1957), reported that aluminum pigmented plastic prevented the soil moisture evaporation by increasing the amount of reflected light.

2.1.3. Effect on soil carbon dioxide

Mulch applied to the surface of the soil is nearly impermeability to carbon dioxide released by roots or decomposition of organic matter in the soil. This could result in the increase of carbon dioxide in the soil and in the air layer between the mulch and soil surface. Hopen and Oebker (1975), reported that carbon dioxide concentrations were higher under polyethylene, paper-polyethylene, and paper aluminum foil mulches than over the bare soil. Baron and Gorske (1981), reported that black polyethylene mulch increased the level of carbon dioxide in the soil to a depth of 5 to

15 centimetres. Sheldrake (1963) *cited* in Hopen and Oebker (1975); as well as Baron and Gorske (1981), noted that carbon dioxide concentration increased four fold at the top of planting holes in mulched soil. This "chimney effect" occurs because the carbon dioxide can only escape through holes or tears in the plastic. Therefore, the crops exist in an enriched environment.

2.2. Optical properties of plastic mulch

Plant growth is based on the exploitation of light energy through photosynthesis. Therefore, both the quantity and the quality of light around the canopy level plays an important role in producing assimilates. According to Jones (1983), the wavelengths of radiation that are important in environmental plant physiology range from 300 nanometre to 100 micrometer and include some of the ultraviolet (UV), the photosynthetically active radiation (PAR), and the infra-red (IR) radiation.

Photosynthetically Active Radiation (PAR) which is characterized by wavelengths of 400 - 700 nanometre plays an important role in plant growth and development (Hart, 1988). PAR is used in process of photosynthesis and stored chemically in high energy hydrocarbon compounds (Rosenberg et al., 1983). Matheny et al. (1992), stated that the quantity of PAR received by the plant strongly affects the rate of photosynthate production, while the quality of PAR influences the distribution of assimilate within the plant. The spectral distribution of upwardly reflected light, particularly the far red to red ratio (FR/R), can alter root/shoot ratios and the amount of nodulation of soybean (Hunt et al., 1989), as well as the yield of tomatoes (Decouteau et al., 1989) by influencing the photosynthate partitioning among the leaves, stems and roots (Kasperbauer et al., 1984).

The ratio of far-red to red is calculated at wavelength of 735 nanometre and 645 nanometre, because these values approach the peaks for phytochrome action spectra in green plant (Bradburne et al., 1989). This is responsible for photomorphogenesis reactions and acts as a regulator and controller in plant growth and development (Ross, 1975). The ratio of far-red and red can affect seed germination, root, stem and leaf growth, flowering,and the efficiency of photosynthesis (Downs et al., 1957; Kasperbauer and Hamilton, 1984).

According to Iqbal (1983) and Hart (1988), ultraviolet radiation, radiant energies of 40 - 400 nanometre, are classified into near ultraviolet/NUV (300 - 400 nanometre), far UV (200 - 300 nanometre), and maximum UV (1 - 200 nanometre). NUV can have moderate photomorphogenetic effect on plant growth and development (Ross, 1975). Near infrared (NIR) radiation which comprises radiant energies from 710 to 4000 nanometre had significant thermal effects and photomophogenetic effects on plant growth and development (Ross, 1975).

Knowledge of the optical properties, e.g. transmittance, reflectance, and absorbance, as a function of wavelength is important for crop production. Optical properties for both short-wave and long-wave radiation are essential in order to perform simple energy balance for plastic films (Likatas et al., 1986). Using the optical properties of a plastic mulch, numerical simulation can be applied to predict the effects of plastic mulch on thermal and moisture regime of the soil (Mahrer, et al., 1984 and Avissar, et al., 1986b), or on the plant canopy (Ham, et al., 1991).

Decouteau et al. (1986, 1988, 1989), reported that the mulch surface colour could change the quantity and quality (spectral balance) of light reaching the plant and could influence plant growth and development.

Decouteau et al. (1990), found that the colour of mulches altered the amount and the wavelength composition of the reflected light. Black mulch reflected less PAR and less blue light, but higher FR/R compared to white mulch (Decoteau et al , 1988). Friend and Decouteau (1990), reported that clear polyethylene transmitted more PAR and blue light than did brown-tinted and white polyethylene. They simply suggested that this was due to the differences in the optical properties of material used. Wavelength selective (infra red transmitted-76) mulch had spectral qualities between black and clear mulch. This type of mulch will absorb most of the light in the PAR region and transmit a large proportion of infra red radiation (Loy et al., 1989; Loy and Wells ,1989).

Optical properties of polyethylene mulch could change as a result of aging or weathering process (Dubois and Brighton, 1978). However, Kluitenberg et al. (1991), reported that optical properties, in the 400 - 1100 nanometre range, of most plastics displayed no change in reflectance, a small (3 to 7 percent) or no decrease in transmittance, and little or no increase in absorbance after four months in the field.

2.3. Plastic mulch and weed control

There are three general classes of weeds; grasses, sedges, and broadleaves. They compete with crop plants for water, nutrients, light, carbon dioxide, and space. Crop-yield losses due to weeds vary, Moolani et.al. (1964), found that pigweed could reduce the yield of corn and soybean as much as 39 percent and 55 percent, respectively. According to Chandler et. al. (1984) *in* Swiader et. al. (1992), in the USA the average annual losses of vegetable crops due to weeds ranged from 7 to 19 percent.

The effects of plastic mulch on weed control effectiveness is largely determined by mulch colour. Clear plastic mulch benefits plant growth by increasing the soil temperatures and conserving the soil moisture, but allows prolific weed growth (Gorske, 1983), because the clear mulch transmits most of the incoming radiation. Norton (1987), reported that all polyethylene mulches, except clear, were effective to control the weed growth in Northwest, USA. Black polyethylene mulch has been found to provide an effective weed control (Kovalchuk, 1983), by preventing light transmission (Swiader, 1992). A study using Infra Red Transmitted (IRT) mulches conducted by Loy and Wells (1990), found an excellent weed control with this product. They concluded that this effect was due to the combination of lower PAR transmission and increased air temperature between soil surface and mulch which increased respiration and reduced leaf chlorophyll levels.

2.4. Plastic mulch and bell-pepper production

All *Capsicum* sp. are warm-season crops, sensitive to cool temperature and will suffer from chilling injury at temperature below 10 ^{o} Celsius (Sundstorm, 1992). It has been well documented that the use of polyethylene plastic mulch could increase the yield of bell pepper in the field (Kovalchuk, 1983; Brown et al., 1986a; Monette and Stewart 1987). These yield increases have been mainly attributed to increases in soil temperature (Clarkson and Fraizer, 1957; Dinkel, 1966; Gerards and Chambers, 1967; Jensen et al., 1990; Patel et al., 1990), water conservation (Baron and Gorske, 1981; Ashworth and Harrison, 1983; Gerber et al.,1983), and reduction of nutrient loss by leaching (Black and Greb, 1962; Jones and Jones, 1978; Locascio et al , 1985)

Relatively little work has been carried out on the influence of mulch colour on plant growth and development. Decoteau et al. (1990), reported that the darker (black and red) the polyethylene mulch used, the less was PAR reflected and the more far-red (FR) relative-to-red (R) was reflected. Porter and Etzel (1982), concluded that yield of bell peppers was increased by using an aluminum-painted mulch, and they suggested that the increase was due to an increase in the amount of reflected photosynthetically active light.

Tomato plants grown with a red polyethylene mulch had higher early and total marketable yield compared with those grown using black, silver and white mulch (Decouteau et al., 1989). Similarly, Brown et al. (1991, 1992), reported that the percentage of marketable tomato fruits was higher in the first harvest from the plants using black or red plastic mulch than from unmulched plants or those with green, aluminum, clear, or white plastic mulch. They suggested the yield differences were due to the increases in soil temperature.

2.5. Plastic mulch and insect/disease Control

Minks and Harrewijn (1987, 1988) have stated that in the temperate climatic zones, aphids are the most important pest insects in agriculture. According to Sundstorm (1992), green peach aphid (*Myzus persicae*) and potato aphid (*Marosiphum euphorbiae*) are the most common aphid species presence in pepper. In addition, the green peach aphid (*Myzus persicae*) is a most important vector of many viral diseases.

Polyethylene plastic mulch has been used as a mechanical method in controlling the presence of aphids in several horticultural crops. According to Kring (1974), aphids are attracted by ultraviolet light. The greater the ultraviolet light was reflected from the mulch surface, the less aphids harboured to the crops. Decoteau et al. (1986, 1988, 1989), found that the colour of a mulch can alter light quality and spectral balance reaching the plant and in turn affect insect behaviour. Carnell (1983), mentioned that covering the soil bed with an opaque mulch which had a one-inch wide shiny stripe provided a good aphid control. Another study conducted by Wyman et al. (1979), concluded that aluminum and white plastic mulch reduced the population of aphid in summer squash planting by 96 percent and 68 percent, respectively. Black and Rolston (1972), reported that reflective mulch controlled aphids more effective than black mulch. Squash plant grown with aluminum reflective mulches were also found to reduce the presence of aphids (Kring, 1964; Johnson et al., 1967; Adlerz and Everett, 1968; Wolfenbarger and Moore, 1968; Schalk et al. 1979) The population of thrips (*Thrips parvispinus* Karny) in hot pepper, have been also controlled using black (Sastrosiswojo, 1991), and reflective mulch (Vos et al. 1991).

Reduction in the number of insects in a crop can decrease the incidence of disease vectored by them. Black and Rolston (1972), found that the lower the aphid population in peppers, the lower the incidence of cucumber mosaic virus. Wyman et al., (1979), reported that squash plants grown with aluminum and white plastic mulch had 94 percent and 77 percent less viral attack than plants grown on bare soil, respectively. Similar results were also reported by Chalfant et al , (1977); Schalk et al., (1979). Work on gladiolus by Johnson et al., (1967) showed that reflective surfaces reduced the spread of cucumber mosaic virus.

Soil pathogens have been controlled by soil solarization. This technique involves covering the bare soil with a transparent polyethylene sheet and allowing the solar radiation to heat the mulch and soil for several weeks (Katan, 1981; Stapleton and DeVay, 1986; Stapleton and Garza-Lopez, 1988).

Katan et al. (1976), solarized an irrigated soil prior to planting in Israel and were able to reduce the population of *F. oxysporum f.* sp. *lycopersici*. Another study by Stapleton and DeVay (1988), found that the population of *Macrophomina phaseolina* (Tassi) Goid was decreased from 62 to 100 percent; *Phytium* spp, 67 to 88 percent; and Gram-positive bacteria, 64 to 99 percent, after six weeks of soil solarization.

III. MATERIALS AND METHODS

The experiments were conducted in 1992 and 1993 at the McGill University Horticultural Research Station, in Ste Anne de Bellevue, Quebec, Canada (45° 26' latitude and 73° 56' longitude).

3.1. EXPERIMENT I

The experiment was designed as a Randomized Complete Block Design (RCBD) with four replications. Five treatments were tested, namely a black nonperforated mulch (BM), black microperforated mulch (MP), wavelength selective/infra red transmitting (IRT-76) green mulch, silver mulch (SM), and bare soil (BS).

The land was fall ploughed and spring harrowed and 1 X 3.5 metre beds formed. A broadcast fertilizer application of 100, 40, and 40 kg/ha of N, P_2O_5, K_2O, respectively was applied. Blocks as well as plots were separated by a one metre wide strip to allow for the passage of field machinery. The treatments were assigned randomly within each block.

Mustard (*Brassica spp*) and rye-grass (*Lolium spp* L) were hand seeded in separate rows within each plot. The rows were spaced 20 centimetre apart, seeds spaced was one centimetre apart within the row. After seeding, the mulch was hand laid and the edges were buried.

At the beginning of the season, each mulch was analyzed for their optical properties. In 1992, at biweekly intervals, a 30 X 25 centimetre piece of plastic was cut randomly from each plot. The plastic was washed, and placed in an envelope. At the end of the growing season, an analyses was made on the optical properties of each plastic sample. In 1993, analysis were made on plastic samples at the start and the end of the season.

For each plastic sample, the transmittance and reflectance were analyzed in 1 nanometre increments over the 390 - 1100 nanometre range using a LICOR-1800 Portable Spectroradiometer combined with LI-1800-12 Integrating Sphere (LICOR, Nebraska). Shortwave absorbance was computed by applying Kirchhoff's law which states that : reflectance + transmittance + absorbance = 1 (Avissar et al., 1986a).

In 1992 when a plastic sample was taken to determine optical properties, percentage germination of the sown mustard and rye-grass seed was calculated in the sample area and in similar size area (30 X 25 centimetres) of the bare soil plot. The number and type of indigenous weeds were also measured. All weed seedlings were cut at ground level and the fresh weights taken. At the end of the season, weed stands (biomass) were measured in the plots.

In 1993, the germination percentage and shoot weights were taken at the first, second, and fourth week after seeding as well as at the end of growing season.

After the plastic was removed and germination counts taken, a soil sample was taken from the centre of each sub-plot at a depth of 15 centimetres. The sample was weighed and then dried at 105 ^{0} Celsius for 24 hours and reweighed. The percentage soil moisture was calculated based on the dried weights.

Soil temperature data were collected using a maximum and minimum thermometre buried in the soil to a 10 centimetre depth. The thermometre was located 17.5 centimetres from the sides of the plot since the temperatures along the steep gradient are usually lower than at the centre (Mahrer and Katan, 1981). Soil temperature data were collected at 0900 daily. The effect of maximum and minimum soil temperature were used to calculate growing degree-days (GDD) which was obtained using the following formula:

GDD = (Maximum Temperature + Minimum Temperature)/2 - 10 ^{o} Celsius

The use of 10 degree Celsius as a base temperature for pepper was based on an experiment conducted by Clavijo (1991).

3.2. EXPERIMENT II

The experiment was designed as a Randomized Complete Block Design (RCBD) with four replications. The treatments used were black mulch (BM), silver mulch-1 (SM-1), silver mulch-2 (SM-2), and bare soil (BS). Previous work indicated that reflective mulch effectively controlled aphid population (Schalk and Robbins, 1987) and increased bell pepper yields (Porter and Etzel, 1982). Therefore, this experiment tried to compare the use of silver mulches with black mulch which has been widely used in bell pepper production.

The field, a clay loam, was fall ploughed, spring harrowed, and a broadcast application of 100, 40, and 40 kg/ha of N, P_2O_5, K_2O, respectively. In 1993, another clay loam site was chosen and fertilized at the rate 80, 40, and 40 kg/ha of N, P_2O_5, and K_20, respectively. These rates were applied following the recommendations outlined by the Conseil des Productions Vegetales du Quebec (CPVQ) for the experimental sites. Experimental plots were in 3.5 X 1 metre. Treatments were assigned randomly within each block. Blocks as well as plots were separated by a 1 metre wide strip to allow for the passage of field machinery. The mulch was hand laid and the edges were buried.

Seeds of pepper cv. Bell Boy were sown on April 23 and 15 in 1992 and 1993, respectively into plastic flats (55 X 28 X 7 centimetre) containing Promix. When the plants had reached the two leaf stage, they were transplanted into 7 X 6 centimetre peat pots filled with Promix. Seedlings were grown in the greenhouse under natural day-length and a constant temperature of 25 ^{0} Celsius. Seedling were watered as necessary. Every week seedlings were fertilized with 200 ppm of 20:20:20 (N, P_2O_5, and K_2O).

Prior to transplanting, in the first week of June, the seedlings were acclimated in a cold frame for three to five days. At planting, the plastic mulch was cut and the plants set in a staggered arrangement with 60 centimetres between plants. There were 11 plants in each plot and the end plants served as guards. A starter solution, 300 ml of 10-52-10 was given to each plant.

Throughout the growing season, plants were hand watered as necessary and weeds between the plot were mechanically controlled.

Aphids were counted twice weekly early in the morning on the third apical leaf of main stem of three plants in the middle of each plot. This leaf was chosen because aphids prefer to settle in the growing leaf (Kennedy et al., 1950). Counting started the last week of June, and continued until a week before the final harvest (September).

In order to study the effect of mulch types on fruit set, flowers were counted weekly on three randomly sampled plants in each plot. At each harvest, fruit numbers were taken from these plants and used to calculate the percentage fruit set.

Fruit was harvested six (August 03, 11, 24, Sept. 01, 11, and 23), and seven times (August 03, 11, 19, 27, Sept. 05, 13, and 21) in 1992 and 1993, respectively. Fruits were classified into marketable and non-marketable groups using the criteria listed in Table 1 and weighed.

Table 1. Pepper fruit classification.

MARKETABLE	- fruit weight over 100 grams - only have small defects (e.g. up to 3 small scratches)
NON-MARKETABLE	- fruit weight under 100 grams - fruit over 100 grams, but with abnormal shape and extensive defects (e.g. blossom and rot, large scratches, rotting, etc.)

- The scheme used was one modified from the classification schemes of Rylski and Kempler (1972) and Rigby (1988).

3.3. ANALYSIS OF DATA

Data were statistically analyzed using PC-SAS (SAS Institute, North Carolina) for the analysis of variances and homogenous data over the years were pooled. Means were separated by the Least Significant Difference (LSD) test as it is a planned comparisons names treatment (Steel and Torrie, 1980).

IV. RESULTS

4.1. Experiment I (1992, 1993)

4.1.1. Optical properties

Optical properties of new materials of the mulches varied only slightly between the years (Table 2). This is probably due to slight differences in the plastic master batches used to form the mulch. The black continuous mulch absorbed more than 94 percent and reflected approximately 5 percent of all incoming radiation (Near Ultra Violet = NUV, Photosynthetically Active Radiation = PAR, and Near Infra-Red = NIR). Similarly, the black microperforated mulch absorbed approximately 95 percent, reflected around 4 percent of all incoming radiation and transmitted small amount of NUV, PAR, and NIR radiation.

The infra red transmitting (IRT)-76 green mulch transmitted 16, and 65 percent in the range PAR and NIR spectra, respectively.

Silver mulch transmitted, reflected, and absorbed radiation in all parts of the spectra approximately equally.

Table 2. Spectral properties (transmittance, reflectance, and absorbance) of new polyethylene mulch materials.

Type of mulch	Transmitted light			Reflected light			Absorbed light		
	NUV	PAR	NIR	NUV	PAR	NIR	NUV	PAR	NIR
	% incident of radiation								
1992:									
1. Black	0.36	0.05	0.20	5.14	5.12	4.99	94.49	94.82	94.81
2. Black micro-perforated	0.44	0.02	0.21	4.11	5.16	5.00	95.45	94.80	94.78
3. IRT-76 green	10.73	16.24	65.47	5.74	6.56	18.24	83.53	77.21	16.29
4. Silver	42.74	39.28	37.28	32.55	30.17	26.92	24.72	30.55	35.80
1993:									
1. Black	-0.36	0.79	3.20	4.93	5.17	4.99	95.44	94.04	91.78
2. Black micro-perforated	-0.28	0.01	0.04	3.70	4.94	4.82	95.44	95.05	95.14
3. IRT-76 green	9.96	14.46	64.82	5.50	6.11	17.46	84.55	79.44	17.71
4. Silver	42.77	39.73	37.44	31.14	28.60	26.09	26.09	31.66	36.47

Note: - NUV = 390 - 399 nanomatre. PAR = 400 - 700 nanometre. NIR = 701 - 1100 nanometre.

Mulches were exposed to the natural field condition for 71 and 107 days in 1992 and 1993, respectively. As the mulches aged, there minor changes in terms of reflectance, transmittance, and absorbance. The differences only at the end of growing season and are presented in Table 3.

IRT-76 green mulch transmitted significantly less light in the NIR range at the end growing season compared with the new material. The IRT-76 green and the black mulches all significantly increased their absorbance of PAR light at the end compared with the beginning of growing season.

Silver mulch significantly reflected less NUV light after a summer exposure in 1993.

Table 3. Spectral properties (transmittance, reflectance, and absorbance) of aged polyethylene mulch materials.

Type of mulch	Transmitted light NUV	Transmitted light PAR	Transmitted light NIR	Reflected light NUV	Reflected light PAR	Reflected light NIR	Absorbed light NUV	Absorbed light PAR	Absorbed light NIR
	---------	---------	---------	% incident of radiation	---------	---------	---------		
1992:									
1. Black	0.05ns	0.02ns	0.08ns	5.30ns	5.04ns	5.19ns	94.65ns	94.95ns	94.73ns
2. Black micro perforated	0.13ns	0.03ns	0.04ns	4.79ns	4.88ns	4.71ns	95.08ns	95.09ns	95.25*
3. IRT-76 green	10.33ns	15.28ns	63.43**	6.03ns	6.06ns	17.66ns	83.64ns	78.66*	20.03**
4. Silver	43.07ns	40.65ns	38.36ns	30.85ns	28.75ns	26.06ns	26.09ns	30.60ns	35.59ns
1993:									
1. Black	0.74ns	0.75ns	2.91ns	5.00ns	5.03ns	4.67ns	94.26ns	94.22ns	92.43*
2. Black micro perforated	-0.04ns	-0.002ns	0.01ns	5.33ns	5.13ns	4.95ns	94.75ns	94.87ns	95.05ns
3. IRT-76 green	8.04ns	14.19ns	63.11**	5.40ns	6.08ns	16.66ns	86.56ns	79.73ns	20.23***
4. Silver	41.77ns	40.37ns	37.94ns	28.88*	28.61ns	25.94ns	29.68ns	31.02ns	36.12ns

Note: - NUV = 390 - 399 nanomatre, PAR = 400 - 700 nanometre, NIR = 701 - 1100 nanometre.
- ns, *, **, *** = nonsignificant, significant at 95 %, 99 %, and 99.9 %, respectively, according to Least Significantly Different at ($p < 0.05$) compared with the new material (Table 2).

4.1.2. Soil temperatures

The polyethylene mulches increased the mean maximum and minimum soil temperatures. The infra red transmitting (IRT-76) green mulch had the highes. mean soil temperatures, followed by silver, black, black microperforated mulch, and bare soil (Table 4).

Table 4. The effect of mulch types on mean soil temperatures (° Celsius).

Treatments	1992 Maximum	1992 Minimum	1993 Maximum	1993 Minimum
14 days after mulch laid:				
1. Bare soil	26.3	16.7	19.9	12.1
2. Black mulch	27.1	17.6	21.1	13.9
3. Black micro-perforated mulch	27.5	17.4	20.9	13.2
4. IRT-76 green mulch	30.0	18.9	23.5	15.9
5. Silver mulch	30.0	18.2	22.6	15.1
Growing season:				
1. Bare soil	26.8	16.9	19.8	12.2
2. Black mulch	27.5	17.8	21.4	14.1
3. Black micro-perforated mulch	27.7	17.5	20.9	13.4
4. IRT-76 green mulch	30.1	18.9	23.9	15.3
5. Silver mulch	29.9	18.8	22.5	15.0

The IRT-76 green mulch also consistently, during the two sampling years, had the highest growing degree day value, followed by the silver, black, black microperforated mulch, and bare soil (Figure 1.).

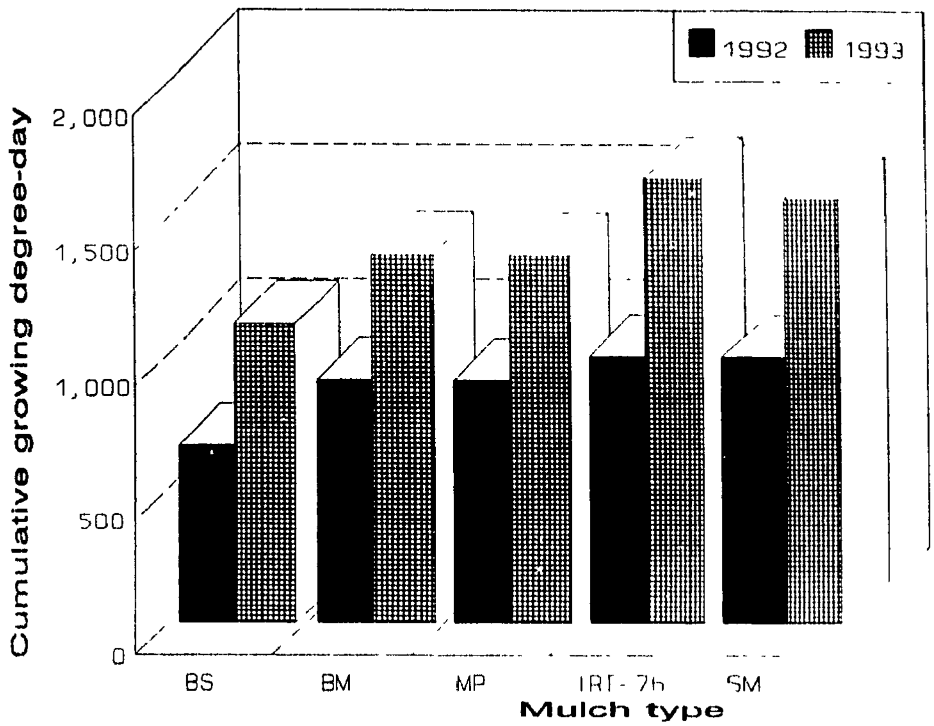

Figure 1. Effect of mulch types (BS=bare soil; BM=black mulch; MP=microperforated black mulch; SM=silver mulch; IRT-76=infra red transmitting green mulch) on cumulative growing degree days (base temperature was 10 ° Celsius, observations conducted for 67 and 96 days in 1992 and 1993, respectively).

4.1.3. Soil moisture content

In 1992, soil moisture content under the solid mulches had 22.3, 154.4, and 127.3 percent more moisture on June 23rd, July 21st, and August 29th, respectively, over the that of the unmulched plot. In July 7th and August 05th, soil moisture content under the solid mulches decreased by 10.6 and 20.2 percent, respectively, over the that of the bare soil (Figure 2a). However, this was only statistically different on July 21st. Increasing or decreasing of soil moisture content under the solid mulches was also followed by the increase or decrease of moisture content under perforated mulch. In 1993, the solid mulches had 12 to 34.7 percent more moisture over the that of the bare soil at the beginning of the season (Figure 2b). However, this was only significantly difference at the June 29th. At the end of the season, the average soil moisture content of the soil under continuous mulches was less than that of the control. Over the 1993 growing season, the microperforated mulch consistently had greater soil moisture content than that of the unmulched plot.

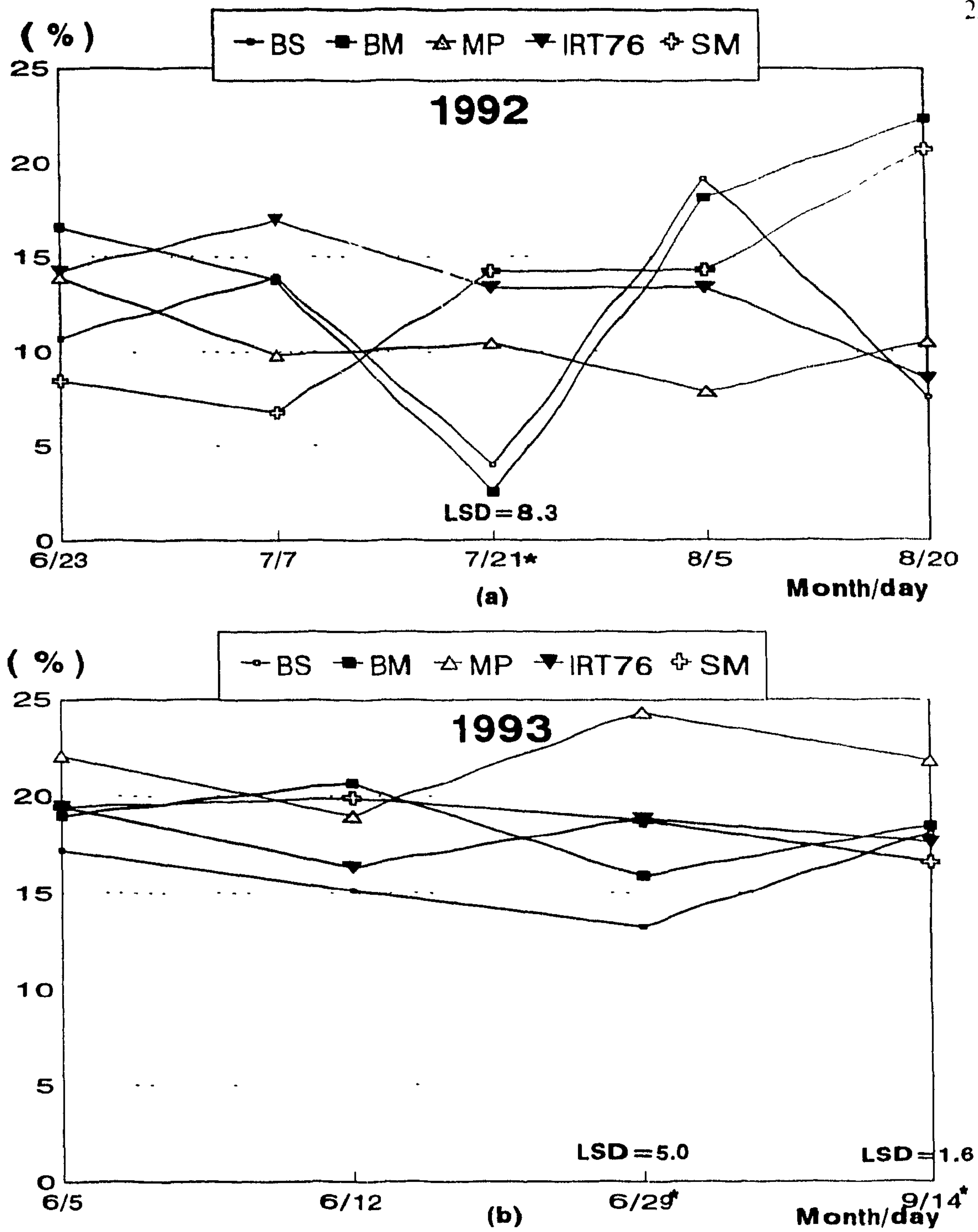

Figure 2. Effect of mulch types (BS=bare soil; BM=black mulch; MP=microperforated black mulch; SM=silver mulch; IRT-76=infra red transmitting green mulch) on percentage of soil moisture content. ("*" sign in the observation dates indicates significantly different among treatments according to Least Significant Different at ($p < 0.05$).

4 1.4. Weed control

Mustard seeds germinated in all the plots and there was initially no significant difference among the treatments in both 1992 and 1993 (Table 5). However, after 30 days no weeds were recorded in the mulched plots. In 1992, the ryegrass germination and emergence pattern was similar to that of the mustard (Table 6). In 1993, there were after 7 days, significantly more ryegrass seedlings found under the mulched rather than the unmulched plot. This situation was transitional and after 30 days no seedlings were recorded under the mulched treatments compared with a 92 percent emergence in the control plots.

Table 5. Effect of mulch type on percentage germination of mustard during a 30 day period.

Treatment	1992			1993		
	7*	14	30	7	14	30
	--------- days after sowing ----------					
1. Bare soil	n/a	49 a	56 a	94 a	98 a	89 a
2. Black mulch	n/a	47 a	0 b	82 a	0 b	0 b
3. Black micro perforated mulch	n/a	47 a	0 b	79 a	1 b	0 b
4. IRT-76 green mulch	n/a	30 a	0 b	82 a	34 b	0 b
5. Silver mulch	n/a	22 a	0 b	89 a	34 b	0 b

a. Values in the same column followed by the same letter are not significantly different according to Least Significant Different test ($p < 0.05$).
b. * = This sampling date was not used in 1992.

Table 6. Effect of mulch type on percentage germination of ryegrass during a 30 day period.

Treatment	1992			1993		
	7*	14	30	7	14	30
	---------- days after sowing ----------					
1. Bare soil	n/a	20 a	67 a	27 a	79 a	92 a
2. Black mulch	n/a	32 a	0 b	76 b	0 b	0 b
3. Black micro perforated mulch	n/a	44 a	0 b	74 b	0 b	0 b
4. IRT-76 green mulch	n/a	29 a	0 a	71 b	37 b	0 b
5. Silver mulch	n/a	23 a	0 b	64 b	59 ab	0 b

a. Values in the same column followed by the same letter are not significantly different according to Least Significant Different test ($p < 0.05$).
b. * = This sampling date was not used in 1992.

The unmulched treatment had significantly greater biomass of both ryegrass and mustard at the end of growing season (Table 7). The silver mulch had significantly more biomass of other weeds (purslane) than did the other mulched treatments, but significantly less than of the control plot.

Table 7. Effect of mulch type on biomass production of mustard, ryegrass, end other weeds at the end of growing season (grams/plant).

Treatment	Mustard		Ryegrass		Other Weeds	
	1992	1993	1992	1993	1992	1993
1. Bare soil	22.5a	31.8a	0.2a	0.4a	28 a	32.9a
2. Black mulch	0 b	0 b	0 b	0 b	0 b	0 c
3. Black micro perforated mulch	0 b	0 b	0 b	0 b	0 b	0 c
4. IRT-76 green mulch	0 b	0 b	0 b	0 b	0.1 b	0 c
5. Silver mulch	0 b	0 b	0 b	0 b	5.8 b	5.5 b

Note: Values in the same column followed by the same letter are not significantly different according to Least Significant Different test ($p < 0.05$).

4.2. Experiment II (1992, 1993)

4.2.1. Vegetative growth

In both 1992 and 1993, plants grown with polyethylene mulches were significantly heavier than non mulched ones. There was no significant difference between the two sampling years (Figure 3).

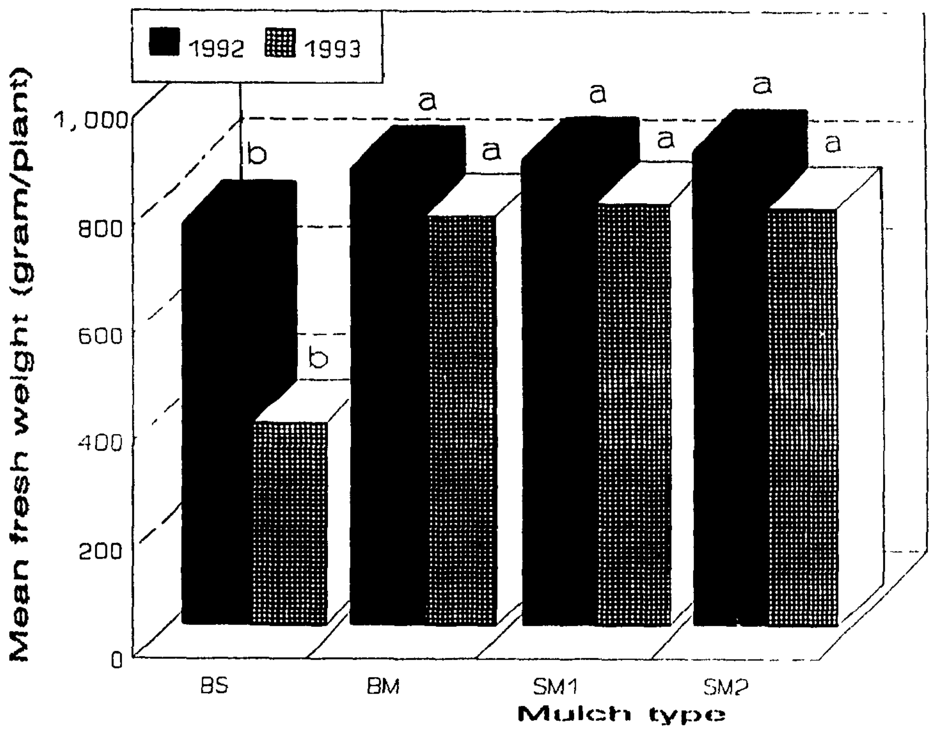

Figure 3. Effect of mulch types (BS=bare soil; BM=black mulch; SM1=silver mulch-1; SM2=silver mulch-2) on mean fresh weight of above-ground portion of pepper plants. Within year columns with the same letters are not significantly different according to Least Significant Different test ($p < 0.05$).

4.2.2. Percentage fruit set

Pepper grown with plastic mulches produced significantly more flowers compared with unmulched plants. However, the percentage fruit set did not differ significantly among the treatments. An F-test for the homogeneity of variances showed there was no statistical different in results between the two years. Both annual and pooled treatment means of percentage of fruit set are presented in Table 8.

Table 8. Effect of mulch types on percentage of fruit set of bell peppers.

Treatments	Percentage 1992	1993	Mean
1. Bare soil	61.2 a	62.0 a	61.6 a
2. Black mulch	57.4 a	65.2 a	61.3 a
3. Silver mulch-1	59.7 a	65.5 a	62.6 a
4. Silver mulch-2	61.7 a	62.5 a	62.2 a

Note: Values in the same column followed by the same letter are not significantly different according to Least Significant Different test ($p < 0.05$).

4.2.3. Early marketable yield

The use of the plastic mulch significantly increased the early marketable yield of peppers compared with those grown in bare soil (Figure 4). There were no significant differences in terms of yield among plants grown with different mulch types. Early marketable yields in 1992 were almost double those of 1993.

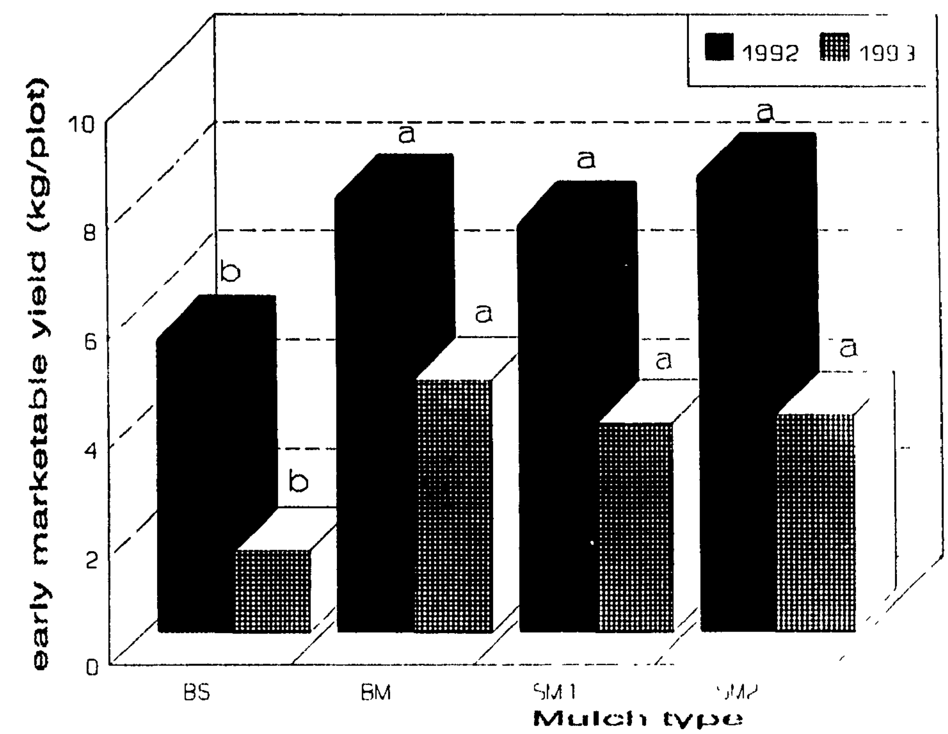

Figure 4. Effect of mulch types (BS=bare soil, BM=black mulch, SM1=silver mulch-1, SM2=silver mulch-2) on early marketable yield of peppers. Within year columns with the same letters are not significantly different according to Least Significant Different test ($p < 0.05$).

Both annual and pooled treatment means of the number of early marketable pepper are presented in figure 5.

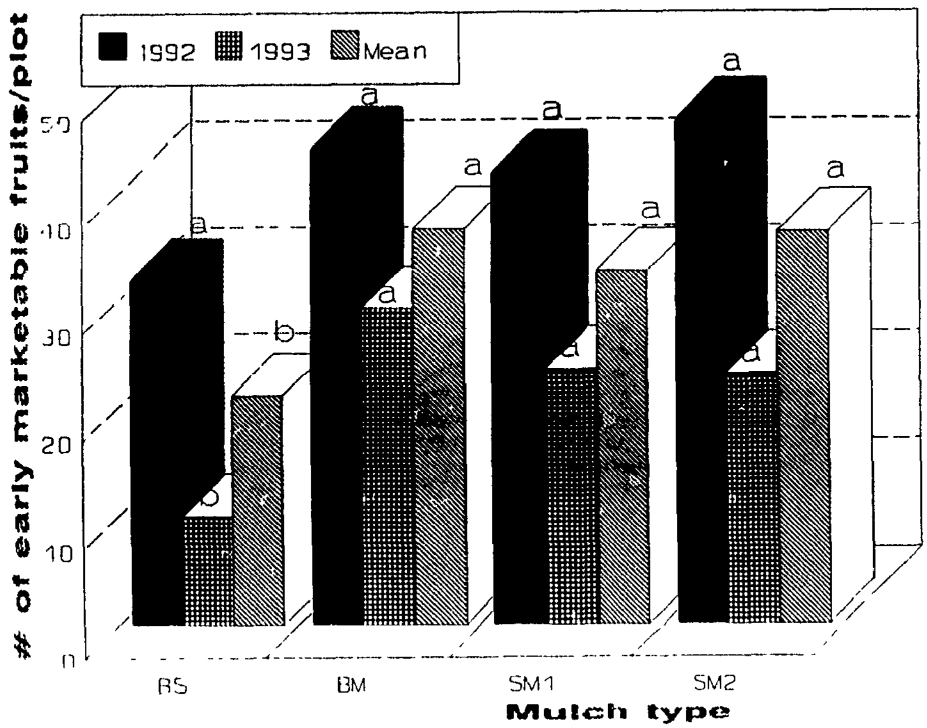

Figure 5. Effect of mulch types (BS=bare soil; BM=black mulch; SM1=silver mulch-1; SM2=silver mulch-2) on the number of early marketable fruits. Within year columns with the same letters are not significantly different according to Least Significant Different test ($p < 0.05$).

There are no interaction between the years and treatments as well as years and blocks. On the average, black mulch produced the highest number of early marketable peppers, then, followed by silver mulch-2, silver mulch-1, and bare soil. Additionally, the number of early marketable peppers harvested 1992 was significantly greater than those of 1993 ($p < 0.05$).

4.2.4. Total pepper yield

Plants grown with polyethylene mulches had significantly greater total marketable yields than the unmulched ones (Table 9). On average, black, silver mulch-1, and silver mulch-2 increased yields by 94.1, 83.8, and 94.1 percent, respectively. Even though results over the years were homogeneous, the mulched plants produced significant greater yields in 1992 compared with 1993 ($p < 0.05$). The use of plastic mulches significantly increased the total number of marketable fruit, which was found to be homogeneous between the two sampling years. In terms of total weight of culls, peppers grown with plastic mulches have been found to be significantly higher than those on bare soil (Table 9). Though results were homogeneous during the two sampling years, the weight of culls obtained in 1992 was significantly greater than that of 1993 ($p < 0.05$). The total fruit number of culls was not significantly different among the treatments, both in 1992 and 1993 (Table 9). The results of the two years were found to be statistically homogeneous to one another. Nevertheless, a statistical analysis of pooled variances indicated that the number of culls of mulched plants was significantly higher than those of bare soil.

Pepper grown using polyethylene mulch had significantly higher Harvest Index, a measure of yield efficiency (Harvest Index = fruit yield/fruit yield + vegetative yield), compared with unmulched plant. In 1993, Although it was not significantly different, the Harvest Index of mulched plant was higher than that of unmulched plant (Table 9).

Table 9. Effect of mulch types on bell pepper production

Treatments	Total fruit: Marketable Number (per/plot) 1992	Marketable Number (per/plot) 1993	Marketable Weight (kg/plot) 1992	Marketable Weight (kg/plot) 1993	Cull Number (per/plot) 1992	Cull Number (per/plot) 1993	Cull Weight (kg/plot) 1992	Cull Weight (kg/plot) 1993	Harvest Index (per/plant basis) 1992	Harvest Index (per/plant basis) 1993
1. Bare soil	58.2a	30.0a	9.8a	3.9a	72.2a	26.0a	7.5a	2.5a	0.72a	0.66a
2. Black mulch	76.8b	79.0b	14.0b	12.4b	69.7a	35.5a	8.5ab	4.5b	0.75b	0.72a
3. Silver mulch-1	72.3b	79.5b	12.7b	12.3b	87.3a	42.3a	10.1c	4.4b	0.75b	0.70a
4. Silver mulch-2	74.8b	80.8b	13.4b	13.0b	76.5a	40.3a	9.5bc	4.5b	0.74b	0.72a

Notes : - Values in the same column followed by the same letter are not significantly different according to Least Significantly Different test at ($p < 0.05$).

4.2.5. Aphid population

Plants grown with plastic mulches had significantly less aphids on them than the unmulched plants. The silver mulched plants had significantly less aphids than those with black mulch. Tests of homogeneity of variances resulted a significant difference number of aphids between the two year experiments (Figure 6).

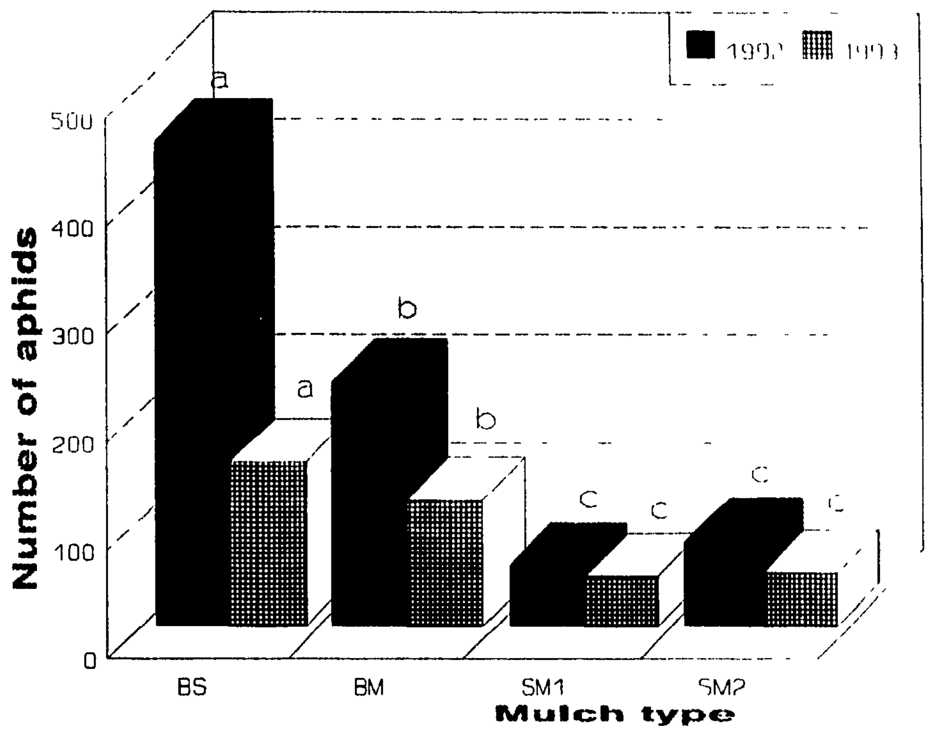

Figure 6. Effect of different type of mulches (BS=bare soil; BM=black mulch; SM1=silver mulch-1; SM2=silver mulch-2) on number of aphids of the third leaf below the apex of peppers (Mean of 3 leaves). Within year columns with the same letters are not significantly different according to Least Significant Different test ($p < 0.05$).

The peak of aphid distributions occurred on July 29-th, 1992 and July 31-st, 1993 (Figure 7).

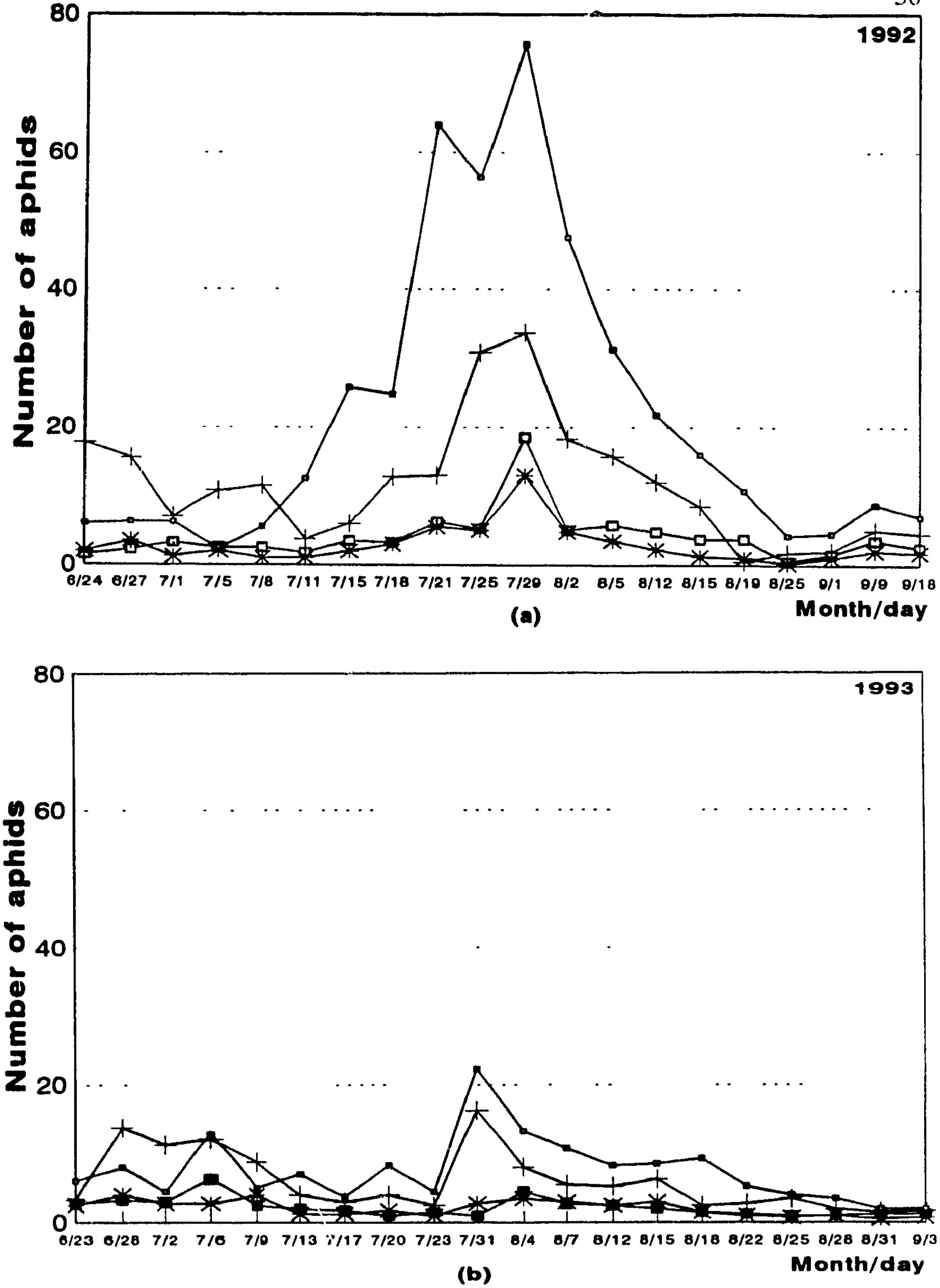

Figure 7. Effect of mulch types (BS=bare soil; BM=black mulch; SM1=silver mulch-1; SM2=silver mulch-2) on seasonal aphid distribution.

V. DISCUSSION

5.1. Experiment I.

Results from 1992 and 1993 studies indicated that aging caused relatively minor changes in transmittance, reflectance, and absorbance of NUV, PAR, and NIR radiation of the tested mulches (Table 3). These results are in agreement with those of Kluitenberg et al., (1991), who reported that plastic mulches showed only small changes in optical properties after four months of field exposure In our experiments, the mulches were in the fields for only 71 and 107 days in 1992 and 1993, respectively. As the plastic aged, it is postulated that it could deteriorate as the length of exposure time increased, since Spice (1974) postulated that UV radiation slowly weakened the optical properties of polyethylene mulch films. Dubois and Brighton (1978), summarized that the stability of a plastic film was influenced by the thickness, type of mulch, duration of exposure, the ultra violet (UV) radiation, oxygen, temperature, and humidity.

The colour of the mulch which results from the additives could influence the rate of degradation. There were few significant changes in optical properties of the IRT-76 green, black and silver mulch during our studies (Table 3). According to Spice (1959), the amount of sunshine received by a clear plastic film proportionally degenerates the photometric properties. However, the presence of the additive chemicals in polyethylene, e.g., the adding carbon black during manufacture and black sheeting, could increase its resistance to sunshine. Perhaps the additive used in the formation of the IRT-76 and the other colour mulches are less stable than those used in the black mulch. A study about the effect of aging on transmission of polyethylene film for greenhouse glazing also had been reported by Giocomelli et al. (1990), who found that transmission in the 1000 to 1100 nanometre waveband increased by 6.2 percent, but decreased in the 300 to 1000 nanometre waveband from 1.8 to 16.4 percent after four years of exposure.

In our trials, the mulch was washed and stored in an envelope to prevent light deterioration. The washing would have removed any soil particles that might have affected light transmission. Dubois and Brighton (1978), indicated that the dirt deposition on mulch tended to decrease light transmission through it.

The use of plastic mulches increased soil temperatures compared with bare soil (Table 4 and Figure 1). The variation between the two sampling years, in addition to the different in number of observation days, might be associated with the fact that air temperature during the 1993 season was warmer than did 1992. In general, the effect of mulch on soil temperatures has been found to be influenced by film colour (Lippert et al., 1964), optical properties (Schales and Sheldrake (1963) *cited* in Lamont (1993), as well as the soil moisture content (Mahrer et al., 1984).

Analysis of optical properties indicated that black mulches absorbed more than 94 percent of NUV, PAR, and NIR radiation. These results were in agreement with Lamont (1993), who summarized that black mulch absorbed most of the UV, PAR, and IR light and re-radiates it to the sky or soil. The high percentage of light absorbed by the black mulch permits conduction of heat energy where the plastic is in direct contact with the soil surface. This results in the increase of soil temperatures.

The IRT-76, a wavelength selective mulch, was designed to selectively transmit most infrared radiation, absorb most visible radiation (Loy and Well, 1989). In our two year studies, the IRT-76 green mulch consistently had the highest average soil temperature and cumulative growing degree days. The higher mean soil temperatures and cumulative growing degree days measured under this type of mulch were probably associated with the higher transmission of NIR radiation (about 65 percent). Similar results were reported by Loy and Wells (1990), who confirmed that soil temperatures under the IRT-76 green mulch were warmer than those under black mulch. In our experiments, silver mulch had higher mean soil temperature than bare soil, black, and microperforated mulches (Table 4, Figure 1). In general, silvered or aluminumized mulch might be expected to produce lower soil temperatures due to the higher amount of light reflectance. In our case, the higher mean soil temperatures under silver mulch might reflect the high levels of NIR transmission (37 percent). Indeed, the study by Decouteau et al., (1986), reported that the mean soil temperatures, at a depth 2.5 cm, under black mulch during three weeks monitoring was only 0.5 degree Celsius higher than under silver mulch.

The moisture in the soil under plastic mulches was consistently higher than that of bare soil and probably resulted from the prevention of evaporation from the soil (Waggoner et al., 1960). Army and Hudspeth (1960), suggested that moisture conservation in the seed zone under plastic films was due to at least two interacting mechanisms; vapour movement and capillary movement. They indicated that during the evening, night, and early morning, moisture in the vapour phase would move in an upward direction, whereas during the day the movement would be downward. However, the net moisture movement in the vapour phase over a 24-hour period was in a downward direction, indicating that the movement of water from lower depths to seed zone was by capillarity. Our trials indicated that black microperforated mulch had high soil moisture content. These levels were may be due to the fact that evaporation rates are slower than the water infiltration rates through the holes. Spice (1959), stated that the use of microperforated mulch allowed a better water percolation into the soil than did a solid mulch.

Polyethylene mulches are generally effective in suppressing weed growth and development. This is seen by the fact that after 30 days no introduced weed seedling were found in any of the mulched plots in 1992 and 1993. Similar results have been also reported by Ricotta and Masinus (1992). Loy and Well (1990), suggested that it was a combination of the suppression of photosynthesis coupled with high soil temperatures that reduced the weed growth under the mulches.

In 1993, there was a significant increase in ryegrass emergence in the mulched plots 7 days after seedling (Table 5). This might be due to mulch related aspects, firstly an increase in soil temperature under the mulch which would provide an optimal germination regime. The Association of Official Seed Analysts (1989), listed the optimum temperatures for ryegrass germination at an alternating 15/25 ^{o} Celsius. Secondly, the higher soil water content under the mulch might have allowed a faster imbibition and increased the germination rate (Anderson, 1983). Indeed, after 14 days the control plot had a germination percentage equivalent to those reported under mulch 7 days earlier.

The presence of purslane, an indigenous species, under the silver mulch might be related to higher transmission values in the range of PAR (Table 2) and the warmer soil temperatures (Table 4). Purslane is a warm season weed species which needs light in order to germinate (Singh, 1973), and germinate in the range of 20 to 45 ^{0} C (Balyan and Bhan 1986).

5.2. Experiment II.

The mean fresh weight of pepper plants grown using plastic mulch were significantly heavier than non mulched plants (Figure 3). Similar results have been reported on a wide range of crops. Salman et al. (1990), reported that black and clear polyethylene mulches increased plant height, and leaf number of cucumbers and cantaloupes. Tomatoes, grown using a black polyethylene mulch were heavier and had an increased leaf area compare with plants grown on silver mulch (Vanderberg and Tiessen, 1972; Decoteau et al., 1986). VanDerwerken and Wilcox-Lee (1988), has found that black mulch increased the plant height and canopy spread of bell peppers. As well, Lee and Yoon (1975), found that mulch increased the final vegetative weight and plant height in peppers. Brown et al. (1986b), reported that black polyethylene mulch significantly increased the mean fresh weight of bell pepper plants.

According to Walker (1979), increasing the soil temperature, even by only one degree celsius would significantly affect plant growth and development. Although it difficult to separate the effects of a mulch on the soil environment, increasing temperature has been regarded as the most important factor in terms of its subsequent affect on growth and development (Flint, 1928; Magruder, 1930; Thompson and Platenius, 1932). Soil moisture conservation under the mulch has also been considered important in promoting the early growth of bell pepper (Gerald and Chambers, 1967; Knavel and Mohr, 1967). Results in our first experiment confirmed that plastic mulch increased soil temperatures and maintained soil moisture content.

Changes in the soil environment such as an increase in soil temperature and moisture content may increase nutrient availability (Ekern, 1967). Several reports indicated that leaching of nitrogen and other nutrients was decreased due to plastic mulch application (Clarkson, 1960; Black and Greb, 1962; Tukey and Schoff, 1961; Jones and Jones 1978). Jones et al. (1977), suggested that the availability of a nutrient was associated with the reduction in soil water percolation. The higher level of nutrients in the soil can lead to an increase in nutrient uptake in peppers (Locascio et al., 1985) and in tomatoes (Sweeney et al., 1987) which may translate into greater vegetative growth.

The improvement of growth of bell pepper might also be associated with an increase of carbon dioxide both at and under the surface of the plastic mulch (Hopen and Oekber, 1975). Practices that increases carbon dioxide slightly or maintains it around plant canopy may be physiologically beneficial to plants. Harper et al. (1973), reported that a field application of carbon dioxide in cotton increased daily net photosynthate production by 33 percent.

As in the first experiment, the polyethylene mulch reduced weed growth. Peppers are very susceptible to weed competition which has been found to reduce yields by 50 to 99 percent (Eshel et al., 1973; Baltajar et al., 1984; Frank et al., 1988; Frank et al., 1992). The decrease of weeds in the crop community will not only reduce competition for the peppers, but also will diminish the presence of host plants for insects and diseases.

Decoteau et al. (1990), reported that peppers grown on mulch with a high ratio of FR/R reflected light were significantly taller and heavier. Plants decreased in size and weight as the mulch used changed from red to black to yellow to white According to Kasperbauer (1987, 1988), a lower FR/R ratio should favour below ground plant parts, whereas a higher FR/R ratio should favour increased shoot size and shoot-to-root biomass ratio.

The spectral analysis of material used in our studies indicated that the ratio of FR/R reflected light of black, silver mulch-1, and silver mulch-2 was 0.99, 0.94, and 0.94, respectively. These values were not significantly different from each other at LSD ($p < 0.05$), and might explain the similarities in above ground of plants grown with these three mulches.

The use of polyethylene mulches significantly increased early and total marketable yields (Figure 4 & 5, Table 9). The yield efficiency of bell peppers which is indicated by Harvest Index was improved due to mulches (Table 9). The higher yield of bell peppers grown on polyethylene mulches compared with those grown on bare soil was probably due to the reflected light from the mulch surfaces. According to Decouteau et al., (1988, 1989), Bradburne et al. (1989), as well as Hunt et al. (1990), the differences in spectral quality of light reflected from different colour of mulches influenced yield through the regulatory effects of the phytochrome systems.

Dufault and Wiggans (1981) as well as Porter and Etzel (1982), suggested that it was reflected light in the PAR range (400 - 700 nanometre) that would be responsible for the yield increases in peppers. Decoteau et al. (1986), found that silver mulches reflected more PAR than black mulch. The ratio of far red to red also influenced the photosynthate partitioning among shoots, roots, and nodules in soybean (Kasperbauer et al, 1984; Hunt et al., 1989) and increased the fruit yield of tomatoes (Decouteau et al., 1988, 1989).

Pepper grown using silver mulch-2 produced greater marketable yields than those grown with silver mulch-1 (Table 9). This was probably due the fact that silver mulch-2 reflected PAR less than did silver mulch-2 (Appendix 3). According to Baker and Musgrave (1963) and Hesketh and Moss (1964), PAR only increased the photosynthate production up to saturation level. The response curve of photosynthate production to PAR is well fitted to a parabolic equation.

As the pepper plants grow and develop, they shade the mulch surfaces and the influence of the mulch declines. However, the effect of mulch is probably most important during the early growth stage of the plant. Rylski (1972) reported that increasing of soil temperatures at the early growth stage of pepper shortened the time between emergence and flowering. Calvert (1959), has shown that the plant light environment during the early vegetative growth of tomato has been found to affect subsequent flowering of tomatoes.

Mulched plants had significantly more flowers than unmulched plants, but the percentage of fruit set was not significantly different among treatments. According to Andrews (1984), a pepper plant has a typical dichotomous branching habits. The plant develops a single main stem until nine to eleven leaves, then the main stem branches off into two or three principle branches. Each of these branches forms two leaves and branches off before the second flower appears. Dichotomous branching repeatedly occurs throughout the plant development. Somos (1984), found that the number of flowers both in the fourth and the fifth branching was 63 percent higher than those on the previous branchings. However, for the fresh market sales commercial pepper are conventionally harvested from the first three branches as fruit from the upper branches do not reach the marketable size (Subramanya, 1983). Perhaps the high proportion of culls reported for the mulched treatments (Table 9) reflect those fruit borne on the upper branches. These fruits would not have time to develop and to reach the marketable size during the restricted growing season. Visual observation indicated that there was a number of fruit borne at each flower cluster. As these fruits grew, they affected each other resulting in the production of misshapen, and hence culled, fruits.

Plants grown with silver mulch had the least number of aphids, followed by black mulched plant and finally those grown on bare soil (Figure 9). Similar finding has been reported by Schalk and Robbins (1987), who found that tomato plants grown with an aluminum mulch had the least number of aphids, followed by black mulched plants and finally those grown on unmulched plots. According to Kring (1972), the mulch surface reflects both short and long-wave light and repels aphids from mulched area. Aphids after first leaving a plant, are strongly attracted to ultraviolet or shortwave light. After flying for a certain time, aphids enter the landing or searching stage. At this stage they are deflected by the shortwave light of the sky and are attracted to long-wave light reflected from plants. Anything that upsets this balance, e.g. mulch reflected light, will cause the aphids to continue their search pattern and avoid the plants.

The effectiveness of silver mulches in repelling the aphids was associated with the high portion of near ultraviolet (NUV) reflection. Silver mulch-1 and silver mulch-2 reflected 32.5 and 33.4 percent of the NUV fraction of the spectrum, respectively (Appendix 3). The more NUV reflected, the less aphids found in plants. The different between these silver mulches to control aphids was may be due to either the different amount of the colour additive or to the gauge of the plastic which might affect its optical properties. Rothman (1967), found that if too little aluminum had been added to mulches in his trials, they would fail to repel aphids.

The black mulch was not expected to provide a good aphid controls. Firstly, since it did not reflect large amount of NUV light (5 percent) and secondly because it optimized plant growth and development. The development of aphids has been shown to be closely correlated with the nitrogen contents of host plant. If the black mulch prevented nitrogen leaching, then more nitrogen would have been available to the plants. A positive correlation has been demonstrated between total and soluble nitrogen, and aphid reproduction (Harrewijn, 1970). However, black mulch control aphids better than bare soil, but less effective than with silver mulches. The black plastics effectiveness might be related in part to its ability to prevent weed growth. Weeds which might act as host plant were not available and this could decrease aphid presence. In the absence of reflected light, temperatures above the mulch could also affect the aphid reproduction. Although data on mulch surface temperatures were not taken in this study, several researchers reported that black mulch could elevate the above mulch surface temperatures (Honma et al., 1958; Hill et al., 1982; Salman et al., 1990). The high temperature might inhibit the aphid reproduction. At the high temperatures (25 - 30° C), the production of aphids was reduced (Lamb and White, 1966; Dixon, 1975; Alleyene and Morrison, 1978).

In our studies, more aphids were found at the early vegetative growth and peaked at the flowering stage (Figure 7). This result was in agreement with an experiment conducted by All et al., (1990). Alleyne and Morrison (1977), reported that in Southern Quebec aphids first appear in the late April or early May.

The effectiveness of the mulch in controlling aphids through light reflection decreases as the plants grow. However, Dixon (1985), indicated that once aphids have settled on a host plant they will autolyse their wing muscles to avoid any accidental dispersal. Therefore, an excellent aphid control at the early stage of vegetative growth probably will reduce the aphid number in the following stages of plant growth. Silver mulches which successfully reduced the number of aphids at the early growth consistently had the lowest number of aphids.

VI. CONCLUSIONS

Aging relatively caused little effect on polyethylene mulch optical properties (transmittance, reflectance and absorbance) after one growing season under the field exposure.

Mean maximum and minimum soil temperatures and cumulative growing degree days under mulches were higher than those of bare soil. The IRT-76 green mulch had the highest mean soil temperature as well as cumulative growing degree days, followed by the silver, black, black microperforated mulches and bare soil. Polyethylene mulches also consistently conserved more soil moisture compared with bare soil.

The presence of a plastic mulch did not significantly reduce mustard emergence, but did reduce the mean fresh weight of seedlings. Initially, ryegrass emergence significantly increased under polyethylene mulches compared with bare soil. However, all polyethylene mulches significantly suppressed both the ryegrass and mustard by at the sampling of period 30 days.

The use of polyethylene mulches significantly increased the mean fresh weight of pepper plants. Plastic mulches also significantly increased early and total marketable yields of bell pepper. On the average, black mulch, silver mulch-1, and silver mulch-2 increased the total marketable yield by 94.1, 83.8, and 94.1 percent, respectively.

The use of polyethylene mulches significantly reduced the presence of aphids in pepper plants. Silver mulches were better than black mulch in reducing the aphid population.

In order to have a better understanding of how mulch spectral qualities influence bell pepper yields, future research should be focused on the areas of :

1. Determination of reflected light effects during the seedling stage on the subsequent growth and development of bell pepper.

2. Determination of reflected light effects on physiological and morphological changes of bell pepper.

3. Determination of relationship among these changes and the yield components.

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APPENDICES

Appendix 1. Examples of analysis of variance tables for the homogenous results between the two sampling years

Example 1. Analysis of variance table for total weight of marketable yield of bell pepper in summer 1992.

Source of variation	DF	SS	MS	F	Pr > F	CV
Model	6	69.4	11.6	4.77	0.0186	12.49
Error	9	21.8	2.4			
Corrected total	15	91.2				
Source	DF	SS	F	Pr > F		
Treatment	3	40.7	5.57	0.0194		
Block	3	28.7	3.96	0.0472		

Example 2. Analysis of variance table for total weight of marketable yield of bell pepper in summer 1993.

Source of variation	DF	SS	MS	F	Pr > F	CV
Model	6	348.8	58.1	46.81	0.0001	7.69
Error	9	11.2	1.2			
Corrected total	15	360				
Source	DF	SS	F	Pr > F		
Treatment	3	345.5	92.74	0.0001		
Block	3	3.3	0.88	0.4857		

Test of homogeneity between the two sampling years was conducted following the method suggested by Gomez and Gomez (1984);

F cal. = Larger EMS/Smaller EMS
therefore; F cal. = 2.4/1.2 = 2

Since F cal. is smaller than F table at 5 % level of confidence, these results were homogeneous to each other. Therefore, these two years data can be pooled to do the statistical analysis.

Appendix 1. (Cont'd)

Example 3. Analysis of variance table for pooled of total weight of marketable yield of bell pepper for two sampling years.

Source of variation	DF	SS	MS	F	Pr > F	CV
Model	13	330.5	25.4	15.98	0.0001	11.04
Error	18	28.6	1.6			
Corrected total	31	359.1				

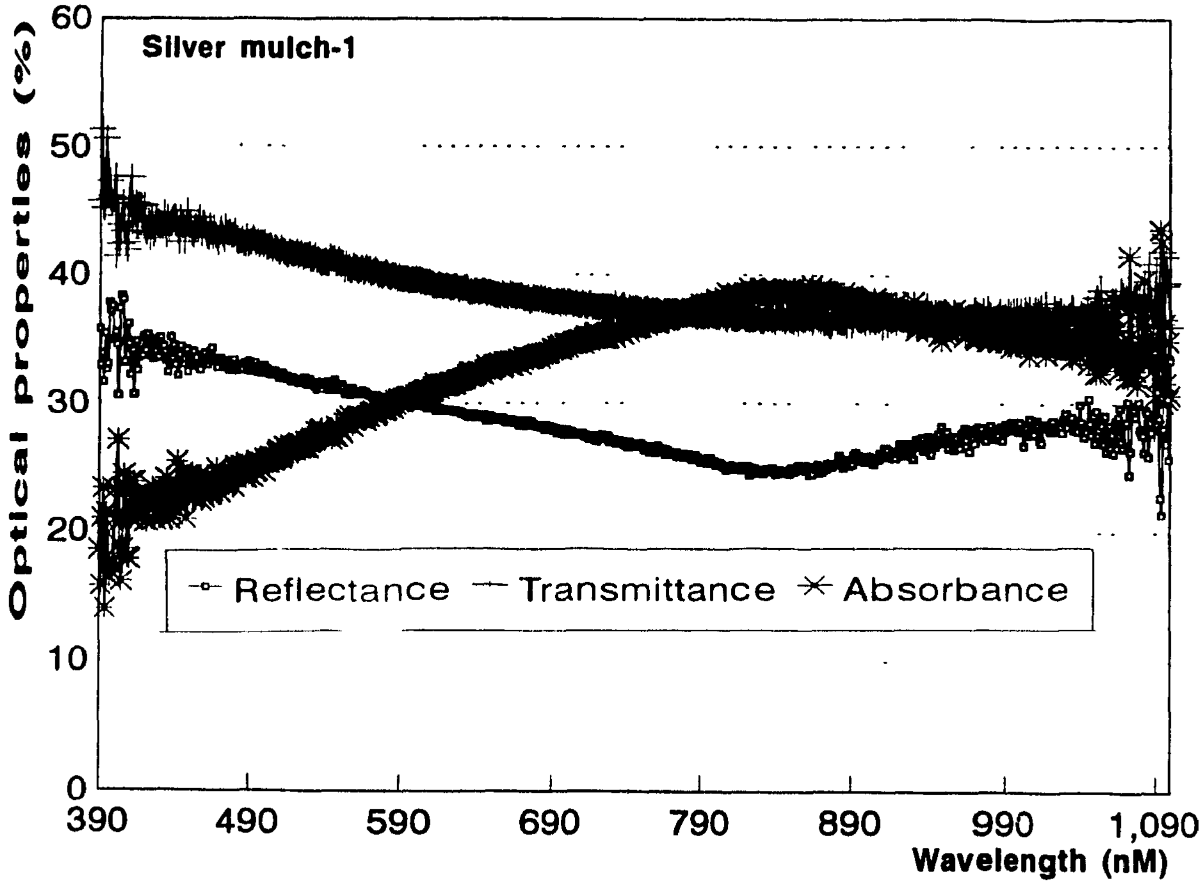
Source	DF	SS	F	Pr > F
Year	1	35	22.01	0.0002
Treatment	3	222.5	46.61	0.0001
Year*Treatment	3	41.1	8.60	0.0009
Block	3	24.8	5.19	0.0093
Block(Year)	3	7.2	1.50	0.2478

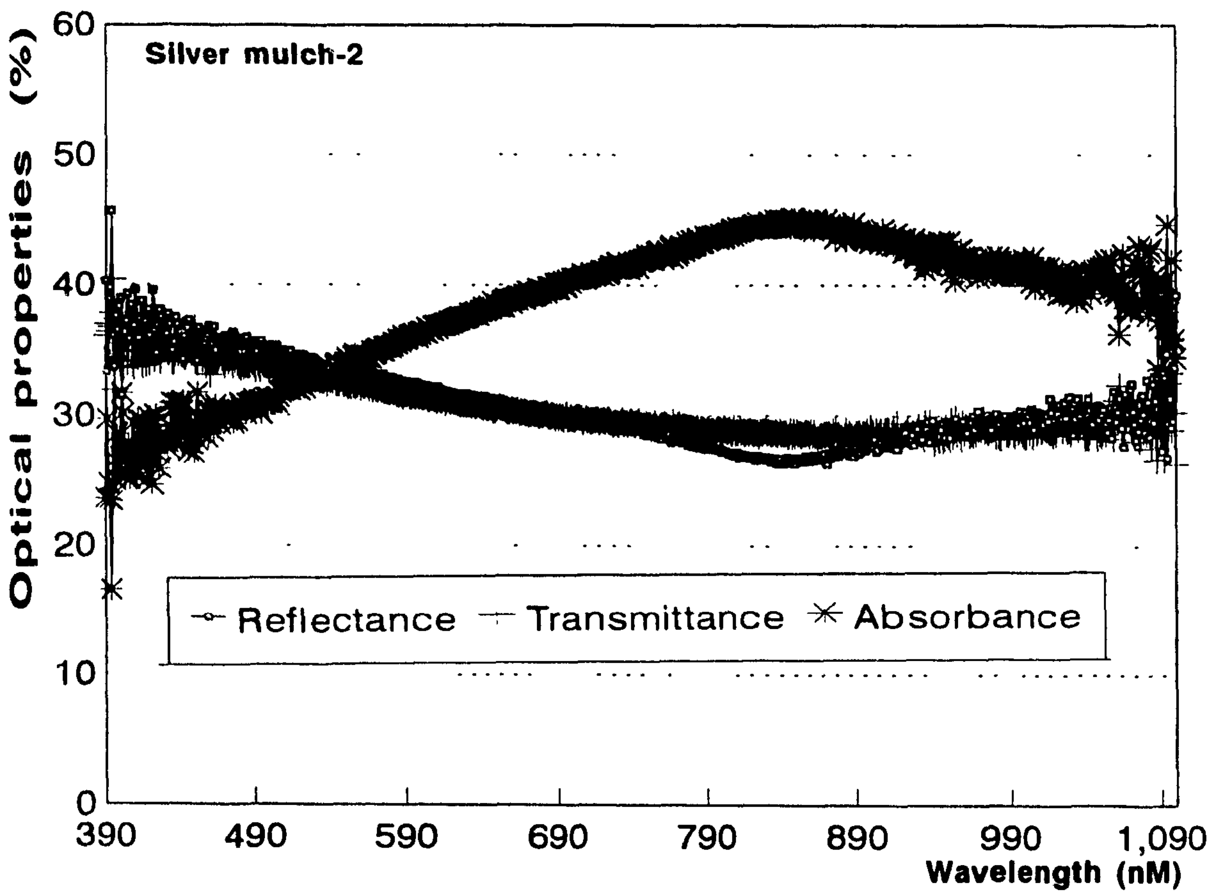
Appendix 2. Precipitation data during the summer 1992 and 1993.
(This data was obtained from weather station
2 kilometre north of the study sites)

Period	Precipitation (mm)	
	1992	1993
May 01 - 15	19.1	36.2
May 16 - 31	42.9	43.1
June 01 - 15	38.4	28.7
June 16 - 30	42.0	44.7
July 01 - 15	77.5	19.0
July 16 - 31	65.4	75.5
Aug. 01 - 15	41.2	46.1
Aug. 16 - 31	12.9*	18.7
Sept. 01 - 15	71.0	84.5
Sept. 16 - 30	34.0	45.6

*) Due to the system upgrading, during this period data was not available for 7 days

Appendix 3. Optical properties of mulch material used in pepper experiment





Appendix 3. (Cont'd)