Effect of Soil Mulches and Herbicides on Production Economics of Warm Season Vegetable Crops in a Cool Climate

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SUMMARY. The efficacy and cost efficiency of using various plastic soil mulches in the production of pepper (*Capsicum annuum* L.), corn (*Zea mays* L.) and muskmelon (*Cucumis melo* L.) were examined over four growing seasons in Saskatchewan, Canada. Clear mulch with or without preemergent herbicides was compared with black or wavelength selective mulches. In all three crops, mulches enhanced yields relative to bare ground in most site–year combinations. Clear mulch usually produced the highest yields. Herbicides applied under the clear plastic provided effective weed control with no observable changes in product efficacy or toxicity to the crop. The weed control provided by the herbicides had no effect on yields in the clear mulch treatments. Consequently, clear mulch without added herbicide usually represented the most cost-effective production option for all three crops.

The use of plastic (polyethylene) films as soil mulches is widespread in horticultural production and is especially common in the production of high value vegetable crops. The impact of mulches on yields and production economics vary with the crop, mulch type used and prevailing environmental and market conditions. Benefits cited from the use of mulches include increased early and total yields (Bonanno and Lamont, 1987; Schales and Ng, 1978), reduced nutrient leaching (Jones et al., 1977) and moisture loss (Bhella, 1988) and improved quality (Sanders et al., 1986). However, mulches represent a significant additional input in terms of both the materials and the labor required for their installation and removal (Gerber et al., 1983). Therefore growers must select the mulch type appropriate for each crop and market situation.

Mulches are available in a range of colors, although clear, black and white represent the most common choices. Clear, and to a lesser extent black mulches, increase soil temperatures while white mulches keep the soil cool (Ashworth and Harrison, 1983). Soil warming is important when warm season crops are being grown in areas with a short growing season or when price premiums for an early crop necessitate planting into cold soil. Although clear plastic is superior to black in terms of enhancing soil temperatures, weeds tend to proliferate under the clear plastic, whereas, black plastic provides effective weed control. Any weeds growing under the clear mulch compete with the crop for nutrients, moisture and space. The potential for competition with the crop is greatest early in the season, as the warm, moist environment provided by the mulch promotes rapid growth of the weeds (Ricketson and Thorpe, 1983). Eventually growth of the weeds is restricted by the limited space available under the mulches or by the shade cast by the developing crop (Ricketson and Thorpe, 1983). Information on the impact of the weed growth under clear mulches on crop performance is limited. Ricketson and Thorpe (1983) found that clear mulch produced superior yields than black plastic in a transplanted tomato (*Lycopersicum esculentum* L.) crop despite extensive weed growth under the clear plastic. However, in a direct-seeded cucumber (*Cucumis sativus* L.) crop, weeds growing under a clear plastic mulch choked out the seedlings (Waterer, 1993).

Problems with weed growth under clear plastic are largely eliminated when fumigants are applied in advance of planting. Although the primary function of fumigation is to control nematodes and persistent soilborne diseases, they also kill or suppress most weeds. At $CDN 800 to 1700 / ha ($US 225 to 480 / acre) (Hamm et al., 1997), fumigation represents an expensive means of weed control. Further, methyl bromide, which is the most popular fumigant for vegetable crop production, is suspected as an ozone depleting substance and its use is being curtailed.

Herbicides represent an alternative method for weed control under clear plastic mulch. To be used under mulches, a herbicide must be designed for preplant incorporation and should provide long-lasting control of a broad spectrum of weeds. The activity of the herbicide and its impact on the crop must not be adversely affected by the changes in soil temperature, moisture, water and air movement caused by the mulch. Information on the use of herbicides in association with mulches and particularly on the impact of mulches on herbicide performance is limited. Some studies indicate that mulches may increase the efficacy of herbicides by reducing losses to volatilization and photodegradation (Gorske, 1983; Jensen et al., 1985, 1989). However, if mulching increases soil temperatures and moisture levels, there may be a corresponding reduction in efficacy related to accelerated breakdown of the herbicide via biological and nonbiological processes (Jensen et al., 1989; Savage, 1977).

Wavelength selective (WLS) mulches represent an alternative solution to the weed control problems experienced with clear mulches. WLS mulches selectively absorb the photosynthetically active radiation required for weed growth while allowing the longer wavelengths responsible for soil warming to pass. This produces a level of weed control comparable to black mulches but with a greater degree of soil warming. WLS mulches are presently more costly than the standard black and clear types.

This study compared the effectiveness and cost efficiency of various soil mulches for the production of three warm-season vegetable crops in a cool, short season environment. The potential for using preplant herbicides

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for weed control under clear plastic mulch was also examined.

Materials and methods

The test crops; muskmelon, pepper and sweet corn were selected for their high value and requirement for warm growing conditions. Trials were conducted in 1994 through 1997 on a Bradwell series sandy loam soil near Outlook, Saskatchewan (51°29'N, Lat.,107°11'W Long., 541-m (1775-ft) elevation) and / or a Sutherland series clay soil in Saskatoon, Saskatchewan (52°8'N Lat., 106°38'W Long., 515-m (1690-ft) elevation). The soil was prepared before planting by discing and rototilling. Sufficient fertilizer was incorporated during the tillage to meet provincial recommendations for each crop (pepper and melon = 100 $kg \cdot ha^{-1}$ (90 lb / acre) of N, 52 $kg \cdot ha^{-1}$ (48 lb / acre) of P and 166 $kg \cdot ha^{-1}$ (150 lb / acre) of K; corn = 80 $kg \cdot ha^{-1}$ (70 lb / acre) of N, 17 $kg \cdot ha^{-1}$ (16 lb / acre) of P and 166 $kg \cdot ha^{-1}$ of K.

The treatments were a) 1.0-mil black mulch (Market Farm Implements, Friedens, Pa.), b) 1.0-mil WLS mulch (IRT 76, Market Farm Implements), c) 1.0-mil clear mulch (Bio-Way Inc., Red Deer, Alta.), d) clear mulch and herbicide, and e) herbicide alone which represented the control treatment. All mulches were 1.5 m (5 ft) wide.

The herbicides were all preplant incorporated, with the mulch applied immediately after incorporation of the herbicide. The herbicides were selected for broad-spectrum activity and suitability for use before weed emergence. Rates for each herbicide represent the midpoint of the recommended concentration range. The herbicides tested and associated application rates were as follows:

Corn = EPTC (S-ethyl dipropyl carbamothioate) a.i. at 1 $L \cdot ha^{-1}$ (13.5 oz / acre) was used in all trials. EPTC provides short-term control of a range of grasses and broadleaf weeds. Limited residual activity of this product allows unrestricted cropping in the next season, which is desirable in market garden production.

Muskmelons = naptalam (2-[(1-naphthalenylamino)carbonyl]benzoic acid) a.i. at 3 $L \cdot ha^{-1}$ (40 oz / acre) was used in 1994 and 1995. Naptalam controls a range of broadleaf weeds. Due to problems with availability of naptalam, DCPA (dimethyl 2,3,5,6-tetrachloro-1,4-benzenedicarboxylate) a.i. at 1.5 $kg \cdot ha^{-1}$ (1.3 lb / acre) was used in the muskmelons in 1996 and 1997. DCPA controls emerging grasses and broadleaf weeds.

Peppers = trifluralin (2, 6-dinitro-N,N-dipropyl-4-[trifluoromethyl] benzenamine) a.i. at 0.5 $L \cdot ha^{-1}$ (6 oz / acre) was used in all trials. Trifluralin controls emerging grasses and broadleaf weeds.

Plots for each crop consisted of 3 m (10 ft) long sections of each mulch treatment laid out in a randomized complete block design with four replicates. The rows were 2.5 m (8 ft) apart. Mulch treatments were applied one week before crop establishment to allow for some soil warming. Trickle irrigation lines installed beneath the mulch were used to maintain soil water potentials above –30 kPa throughout the growing season.

Pepper and corn trials were conducted at the Outlook site in 1994 and 1995 and at both sites in 1996 and 1997. Six-week-old pepper seedlings ('Calwonder 300' in 1994, 'Redstart' in 1995 and 'Staddon's Select' in 1996 and 1997) were transplanted into the field in late May or early June. Plants were spaced 20 cm (8 inch) apart in the row. Each row was covered with a spunbonded polyester row covering (Reemay, Ken-Bar, Reading, Mass.) draped over 30-cm (12-inch) tall wire hoops. The row covers were removed in early July. A late-maturing, supersweet type corn ('Northern Supersweet' in 1994, 'Challenger' in 1995 and 'Eagle' in 1996 and 1997) was seeded by hand through the mulch in late May. The seed was placed at 15 cm (6 inch) intervals in twin rows spaced 30 cm (12 inch) apart. The muskmelon trials were conducted at the Saskatoon site in all test years and also at Outlook in 1997. Fifteen-day-old melon seedlings ('Earligold') grown in peat pots (Jiffy Products, Batavia, Ill.) were transplanted into the field in early June. Plants were spaced 20 cm (8 inch) apart in the row. The melon seedlings were covered with floating row cover (Agryl P-17, Agricultural Supply, Escondido Calif.) until the onset of flowering in early July.

Weed growth under the different mulch treatments was estimated in each crop in July and again in August. At each sampling date, four 1000-cm^2 (155-$inch^2$) quadrats were randomly selected within the mulched area of each row . The quadrats were evaluated for the species composition of the weed population and the proportion of the soil surface covered by weeds.

The corn was harvested twice weekly at cob maturity until frost or full harvest. Early yield for the corn crop was defined as yield through the first week of September. Melons were harvested twice weekly at full slip. Peppers were collected in a once over harvest just before the first fall frost. Marketable yields were based on Agriculture and Agri-food Canada specifications. All yields reported represent marketable commodity.

Data were analyzed using the analysis of variance (ANOVA) pro-

Table 1. Growing season climatic characteristics for the Saskatoon and Outlook test sites from 1994–97.

Climate	1994	1995	1996	1997	30-Year avg
Saskatoon					
Temperature (°C)[z]	15.7	15.3	15.5	16.2	15.6
Sunshine (h)	240	247	272	286	278
Fall frost[y]	13 Oct.	16 Sept.	10 Sept.	29 Sept.	20 Sept.
Outlook					
Temperature (°C)	16.7	16.3	16.2	17.0	16.7
Sunshine (h)	265	268	267	290	282
Fall frost	19 Oct.	19 Sept.	29 Sept.	5 Oct.	23 Sept.

[z]Average from 15 May to 15 Sept.; °F = 1.8(°C) + 32.
[y]First occurrence of temperatures below –1°C (30 °F).

Table 2. Marketable fruit yields for peppers produced with different soil mulch and herbicide combinations.

Soil mulch and herbicide combination	1994	1995	1996 (kg·m^{-1} of row)[z] Saskatoon	1996 Outlook	1997 Saskatoon	1997 Outlook	Mean 1994–97
Clear	0.9	5.1	4.5	3.1	6.2	6.4	4.4
Clear + herbicide	1.5	1.5	4.9	3.3	6.9	7.0	4.2
Wavelength selective	2.3	3.2	5.1	2.7	5.8	6.5	4.3
Black	2.2	4.1	3.7	2.2	6.0	6.6	4.1
Herbicide only	0.8	0.3	3.7	1.7	4.3	4.4	2.5
LSD$_{(0.05)}$	1.5	1.0	1.6	0.8	0.7	1.4	
CV (%)		54	23	14	20	14	22

[z]1.0 kg·m^{-1} = 0.67 lb / ft.

gram of SAS (SAS Institute, 1990). Data for percentage ground coverage by weeds were subject to arcsin conversion before analysis. Error variances for the yield components were highly heterogeneous for sites and years; therefore those data were analyzed and presented separately. When the analysis of variance indicated significant treatment effects, the treatment means were compared using Fisher's protected LSD test.

Basic costs of production were calculated for each crop along with the additional costs associated with the mulch and herbicide treatments (H. Clark, personal communication) Basic costs include fertilizers, pesticides, seed or transplants, irrigation, taxes, overhead and labour. The costs for the mulch and herbicide treatments include the cost of materials as well as the labour involved in applying and removing the mulches and applying the herbicides. All material costs are based on 1997 commercial or bulk prices, freight on board Saskatchewan in \$CDN. Labour costs are based on a wage of \$CDN 5.50 / h (\$US 3.68 / h). Break-even prices for the various mulch treatments were determined based on the average yield for each treatment over all site and year combinations. The break-even price represents the price per kilogram that must be obtained to cover all costs and was calculated by dividing the total cost into the marketable yields.

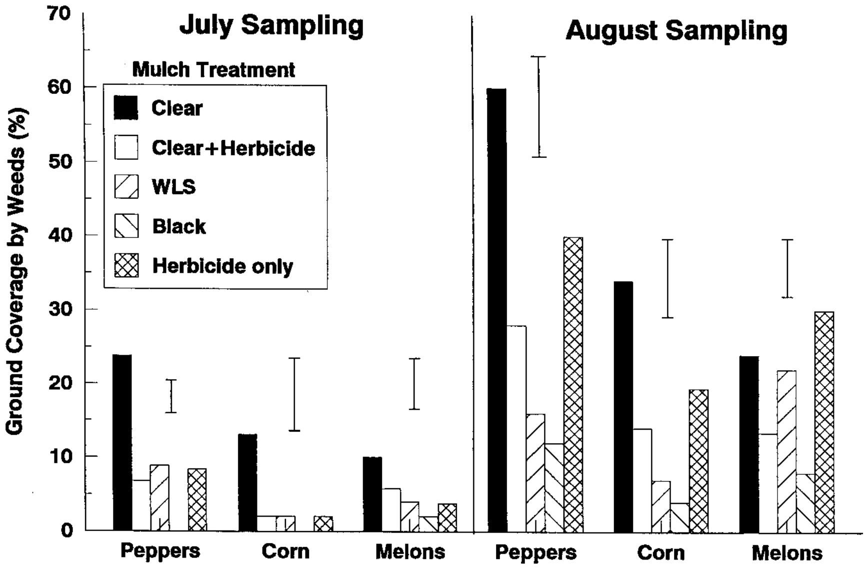

Fig. 1. Percentage ground coverage by weeds for pepper, corn and melon crops as influenced by plastic mulch and herbicide treatments. Data averaged for 1994–97. Bars represent LSD values at P = 0.05. WLS = wavelength selective.

Results and discussion

WEATHER CONDITIONS. Cloudier than normal conditions slowed crop development in 1994 (Table 1), however, the lateness of the first fall frost allowed the majority of the crops to mature. Conditions in 1995 were similar to 1994, but without the long open fall. In 1996, unusually warm weather

Table 3. Early and total cob yields for corn produced with different soil mulch and herbicide combinations.

Soil mulch and herbicide combination	1994 Early[z]	1994 Total	1995 Early	1995 Total	1996 Saskatoon (kg·m^{-1} row)[y] Early	1996 Saskatoon Total	1996 Outlook Early	1996 Outlook Total
Clear	3.3	4.4	0.5	3.2	1.5	3.7	1.4	3.5
Clear + herbicide	3.7	4.6	1.2	1.3	1.5	4.0	0.6	3.3
Wavelength selective	2.2	3.8	0.3	0.9	0.5	2.7	0	2.7
Black	3.5	5.3	0.3	0.7	0.2	2.8	0	2.3
Herbicide only	1.7	3.3	0	0.2	0.3	2.8	0	2.8
LSD$_{(0.05)}$	0.8	0.9	0.5	0.8	0.6	0.5	0.5	0.5
CV (%)		16	21	20	17	26	14	20

[z]Early = before first week of September.
[y]1.0 kg·m^{-1} = 0.67 lb / ft.

in August compensated for poor conditions earlier in the year. Frost came early in Saskatoon in 1996. The 1997 growing season was warmer than normal, with abundant sunshine and a long frost-free fall.

WEED CONTROL. Broadleaf annual weeds such as lambsquarters (*Chenopodium album* L.), red root pigweed (*Amaranthus retroflexus* L.) and prostrate pigweed (*A. graecizans* L.) were predominant in terms of both species diversity and plant numbers in the test plots. This is fairly typical of commercial vegetable fields as the herbicides registered for use in most vegetable crops are more effective against grasses than broadleaf weed species. The extent of ground coverage by weeds in the mulch and herbicide treatments was similar in the various site and year combinations and the data were pooled accordingly (Fig. 1). Ground coverage by weeds was more extensive in the pepper plots than in the melon or corn plots. The peppers produced a much sparser canopy than the melons or corn, which allowed establishment and growth of weeds. In the corn and pepper plots, weed growth under the nontreated clear plastic mulch was substantially greater than any other treatment. Clear plastic mulches warm the soil and conserve soil moisture while also transmitting light, resulting in conditions ideally suited for weed development (Ricketson and Thorpe, 1983). The shade produced by the sprawling melon crop appears to have reduced weed growth when clear plastic mulch was used without herbicides. Jensen et al. (1989) found that the weed species composition was influenced by the use of clear mulch. Species such as purslane (*Portulaca oleracea* L.) which are adapted to high temperatures and have a relatively prostrate growth habit thrived under the mulches while other species disappeared. No such shift in weed species diversity was noted under the clear plastic in this trial. In all three crops, applying herbicide under the clear plastic mulch provided a degree of weed control equivalent to the black and WLS mulches. No single weed species dominated the population that developed in the herbicide treated areas.

PEPPERS. In 1994, variability in crop vigor and yields was high across the trial (CV for yields of 54%) and no significant differences in yield potential for the various mulch and herbicide combinations were apparent (Table 2). In 1995, plants in both treatments receiving the herbicide were stunted and chlorotic for the duration of the growing season. The symptoms were characteristic of trifluralin damage, yet the product, which is registered for use on peppers, was applied according to recommendations. The degree of damage was not influenced by the presence of the clear mulch. This indicates the problem was not related to changes in herbicide activity or crop tolerances caused by the mulch treatment. Similar herbicide treatments produced no crop damage in the other cropping seasons. Although weed growth was extensive under the clear mulch with no added herbicide, that treatment produced the greatest fruit yields in 1995 followed by the black and WLS mulch treatments (Table 2). Yields for the clear + herbicide and herbicide alone treatments lagged well behind the other treatments in 1995. In 1996, there were no significant differences in fruit yields between the various treatments at the Saskatoon site (Table 2). In Outlook, the two clear mulch treatments produced the highest yields, while the nonmulched control produced the lowest yields. In 1997, the mulched treatments produced greater yields than the nonmulched controls at both sites (Table 2). In Saskatoon, the combination of clear mulch + herbicide increased yields relative to the other mulch treatments, but no corresponding response was observed in Outlook.

CORN. Corn planted on the clear mulch treatments consistently emerged several days earlier than any of the other treatments, but the final germination percentages were uniformly high for all treatments (data not shown). Yield responses to the mulch treatments varied between test years. In 1994, all mulch treatments except the WLS improved early and total cob yields relative to the nonmulched control (Table 3). In 1995, the combination of herbicide with clear mulch enhanced early but not the final yields. The two clear mulch treatments produced the best total yields at both test sites in 1996 and also enhanced early yields (Table 3). Using the WLS and black plastic mulches did not improve yields relative to the nonmulched control in 1995 or 1996 (Table 3). In 1997, the clear plastic mulch again enhanced early yields at both sites (Table 3). Total yields in Saskatoon were higher on the clear mulch without herbicide than when WLS or black plastic was used. In Outlook, all mulched treatments produced higher yields than the control.

MELONS. In all test seasons, vegetative growth (vine length) of the crop was enhanced by the mulch treatments, with the clear mulch providing the greatest benefit (data not shown). In 1994 and 1995, there were no significant differences in fruit yields among the mulched treatments, but the mulched treatments produced an average of 92% and 77% more fruit than the nonmulched controls in the two seasons (Table 4). In 1996, the two treatments with clear mulch yielded, on average, 63% more than the other treatments (Table 4). The black and WLS mulches did not improve yields relative to the control in 1996. In 1997, there were again no significant differences in fruit yields among the mulched treatments, but the mulched treatments produced an average of 51% and 73% more fruit than the nonmulched controls at the two trial sites (Table 4).

1997				Mean	
Saskatoon		Outlook		1994–97	
Early	Total	Early	Total	Early	Total
5.4	5.8	2.4	4.7	2.4	4.2
4.4	4.9	2.1	4.8	2.2	3.8
2.2	4.2	2.1	4.1	1.2	3.0
2.9	3.8	0.8	4.0	1.3	3.2
3.0	4.8	0.2	2.9	0.9	2.8
1.1	1.3	1.0	0.8		
12	21	18	24	11	

ECONOMICS. The mulch and her-

Table 4. Marketable fruit yields for muskmelons produced with different soil mulch and herbicide combinations.

Soil mulch and herbicide combination	Fruit yield (kg·m^{-1} of row)[z] 1994	1995	1996	1997 Saskatoon	1997 Outlook	Mean 1994–97
Clear	10.9	7.2	9.5	26.3	23.7	15.5
Clear + herbicide	8.5	7.5	9.1	27.2	22.9	15.0
Wavelength selective	10.6	7.1	6.8	22.9	21.3	13.7
Black	10.8	5.8	4.8	20.1	18.6	12.0
Herbicide alone	5.3	3.3	3.9	15.8	12.5	8.1
$LSD_{(0.05)}$	2.5	2.5	4.5	4.5	4.5	
CV (%)		14	17	26	12	12

[z]1.0 kg·m^{-1} = 0.67 lb / ft.

Table 5. Basic cost of production for drip irrigated pepper, corn and melon crops and cost of associated mulch and herbicide treatments.

Crop	Basic cost ($CDN/m of row)[z]	Mulch treatment	Mulch/herbicide cost ($CDN/m row)
Pepper	$1.11	Clear	$0.05
Corn	$0.23	Black	$0.05
Melon	$0.88	Wavelength selective	$0.14
		Herbicide alone	$0.01

[z]$CDN 1.00 / m = $US 0.20 / ft.

bicide treatments represented a relatively minor component of the total production cost for the pepper and melon crops, but added considerably to the cost of producing the corn crop (Table 5). All the mulch treatments reduced the break-even price required for the pepper crop relative to producing the crop without mulches (Table 6). Differences in cost per unit fruit production between the mulch treatments were small but based on the average for the six site–year combinations, the clear mulch with no added herbicide had the lowest cost per unit fruit production.

Based on the six site–year combinations, mulches of all types generally improved corn yields and earliness relative to the nonmulched control. The clear plastic mulch with or without herbicide usually produced superior early and total yields and therefore represented the most cost effective production option (Table 6). The clear mulch was particularly cost effective when the objective was early production. The wavelength selective mulch represented a less cost effective production option for corn than growing without mulch.

Over the 4 years of testing, the mulches increased melon yields by an average of 73% relative to the nonmulched controls. There was no consistent difference in melon yields among the various mulch treatments. All mulches reduced cost per unit fruit produced relative to the nonmulched controls (Table 6), with the clear mulch with or without herbicide having the lowest cost per unit of fruit yield.

This study demonstrated that in temperate production zones with a short growing season, clear plastic mulches generally represented the most effective means for enhancing yields and profitability of production of warm season vegetable crops. The enhancement in yields is likely due to the higher soil temperatures produced by the clear mulches. Soil warming associated with the use of clear mulches is particularly important when slow-maturing warm-season crops such as melons and peppers are grown in regions, such as Saskatchewan, as the brevity of the growing season necessitates early planting. Soil warming by clear mulches is also valuable in crops, such as corn, where earliness in production brings a substantial price premium.

The potential for excessive weed growth is a concern whenever clear plastic mulches are used on nonfumigated soils. This study showed that herbicides applied under the clear mulch at standard recommended rates provided effective weed control with no observable changes in herbicide efficacy or crop toxicity relative to nonmulched areas. This indicates that

Table 6. Crop cost, average yield and break even price for peppers, corn and melons as influenced by differing soil mulch and herbicide combinations.

Soil mulch and herbicide combination	Pepper: Crop cost[z] ($CDN/m)[w]	Pepper: Yield[y] (kg·m^{-1})[w]	Pepper: Break even[x] ($CDN/kg)[w]	Corn: Crop cost ($CDN/m)	Corn: Yield (kg·m^{-1}) Early	Corn: Yield Total	Corn: Break even ($CDN/kg) Early	Corn: Break even Total	Muskmelon: Crop cost ($CDN/m)	Muskmelon: Yield (kg·m^{-1})	Muskmelon: Break even ($CDN/kg)
Clear	1.16	4.4	0.26	0.28	2.4	4.2	0.12	0.07	0.94	15.5	0.06
Clear + herbicide	1.17	4.2	0.27	0.29	2.2	3.8	0.13	0.08	0.95	15.0	0.06
Wavelength selective	1.25	4.3	0.29	0.37	1.2	3.0	0.31	0.12	1.02	13.7	0.07
Black	1.16	4.1	0.28	0.28	1.3	3.2	0.21	0.09	0.94	12.0	0.08
Herbicide only	1.12	2.5	0.45	0.24	0.9	2.8	0.27	0.09	0.89	8.1	0.11

[z]Based on calculations presented in Table 5.
[y]Average over all site year combinations.
[x]Crop cost / yield.
[w]$CDN 1.00 / m = $US 0.20 / ft, 1.0 kg·m^{-1} = 0.67 lb / ft, $CDN 1.00 / kg = $US 0.30 / lb.

herbicides may represent a cost effective and environmentally sound alternative to fumigants where weeds represent the primary pest problem in the crop. The weed control provided by the herbicides or by the more opaque mulches did not improve yields relative to clear mulch with no herbicide in this study. Intensive irrigation and fertility management may have reduced the potential for competition between the crop and the weeds growing under the clear mulch for these production factors. Weed growth under clear mulches may be more of a concern in less intensively managed situations especially if the initial weed population is larger or comprised of more competitive species. In this study, establishment and early growth of the pepper and melon crops was promoted by the use of transplants and field covers. Similarly, seeding of the corn was delayed until air and soil temperatures were conducive to rapid growth. These management factors provided the crops with an early competitive advantage over any emerging weeds. Weed control via the application of herbicides or the use of opaque mulches may be more important when slow developing crops are direct seeded or when adverse conditions retard development of the emerging crop relative to the weeds.

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