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Black Polyethylene Mulch Doubled Yield of Fresh-market Field Tomatoes

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Abstract. **Field experiments were conducted to a) maximize total yield of fresh-market field tomato *(Lycopersicon esculentum* Mill.) cultivars using black polyethylene mulch (BPM), and b) increase fruit size and yield during the last 5 weeks of the production period by reducing the number of synthate sinks per plant through eliminating all flowers that appeared during this period. Unmulched treatments under trickle irrigation and multiple applications of soluble fertilizer yielded an average of 43 t·ha^{-1} for 'Sunny' and 'Pik-Rite' over the two planting dates. With BPM, total yield increased by 95% to 84 t·ha^{-1}. Although total yield increases due to BPM over the control were highly significant in both cultivars and over the two planting dates, yield increases were higher for the early than for the optimum planting date. BPM also significantly increased early production of 'Pik-Rite' but not 'Sunny', and the increase in early production was more pronounced for the optimum than the early planting date. Sink reduction during the last 5 weeks of the growing season had no effect on yield or fruit weight during that period.**

Although a wide variety of synthetic and organic mulches has been evaluated (Ashworth and Harrison, 1983; Decoteau et al., 1989; Wien, 1981), black polyethylene mulch (BPM) has the widest use as a mulch in the production of fresh-market field tomatoes (Hochmuth et al., 1986). Beneficial responses of tomatoes to BPM include higher total yield (Bhella, 1988; Decoteau et al., 1989; Wien and Minotti, 1987), earlier production (Bhella, 1988; Kearney and Coffey, 1982; Perry and Sanders, 1986; West and Pierce, 1988), and better fruit quality (Perry and Sanders, 1986; Wien and Minotti, 1987). These favorable economic plant responses have been attributed, in part, to greater efficiency of water and fertilizer use (Jones et al., 1977; Sweeney et al., 1987), reduced competition with weeds (Smith, 1968; Teasdale and Colacicco, 1985), higher soil tem-

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Table 1. Effect of black polyethylene mulch (BPM) on total yield and early fruiting of 'Sunny' and 'Pik-Rite' fresh-market tomatoes from early and optimum planting dates.

Treatment	Cultivar	Planting date	Total yield ($t \cdot ha^{-1}$)	Early fruiting ($t \cdot ha^{-1}$)
Mulched (BPM)	Sunny	Early	87.4	4.52
	Sunny	Optimum	87.5	3.68
	Pik-Rite	Early	85.1	7.68
	Pik-Rite	Optimum	74.7	7.96
Unmulched	Sunny	Early	43.1	4.84
	Sunny	Optimum	48.9	2.69
	Pik-Rite	Early	41.5	5.64
	Pik-Rite	Optimum	38.4	1.51
LSD			10.2	2.09

Table 2. Analysis of variance for total yield and early fruiting.

Source of variation	df	Total yield		Early fruiting	
		F value	Significance	F value	Significance
Mulch	1	261.32	**	11.87	**
Date	1	0.57	NS	5.45	*
Mulch × date	1	1.66	NS	3.22	+
Cultivar	1	7.28	**	19.01	**
Cultivar × date	1	3.65	NS	0.30	NS
Mulch × cultivar	1	0.09	NS	7.85	**
Mulch × date × cultivar	1	0.03	NS	0.28	NS

NS,+,*,**Nonsignificant or significant at $P = 0.10$, 0.05, and 0.01, respectively.

peratures (Ashworth and Harrison, 1983; Bhella and Kwolek, 1984; Decoteau et al., 1989), reduced soil pathogens, and breakdown of phytotoxic substances (Katan et al., 1976). Additional increases in yield under BPM over bare soil were attained when trickle irrigation (Bhella, 1988; Cook and Sanders, 1991; Lin et al., 1983) and multiple applications of fertilizer (Black and Greb, 1962) were used through the trickle system.

Fruit size in fresh-market tomatoes is a major determinant of market price. Tomato plants generally bear large fruits during the early part of the production season, and fruits become smaller during the later part of the season. In most cases, in greenhouse-produced tomatoes, removal of axillary shoots early in the season has been shown to increase early fruiting and fruit size (Brown et al., 1971; Decoteau, 1990). We postulated that size of fruits that develop during the later part of the growing season in the field (August through September) will increase with a concomitant increase in yield, if all subsequent flowers formed during this period are eliminated. This assumption is based on the fact that developing fruits and vegetatively growing shoots are major synthate sinks and that by eliminating newly formed flowers, more assimilates will be directed to already growing fruits, thus leading to an increase in fruit weight.

This study was undertaken to a) determine the effect of BPM on total yield and early fruiting of two fresh-market, field-grown tomato cultivars irrigated and fertilized through a trickle irrigation system at weekly frequencies and b) assess the effect of sink reduction, through the elimination of flowers that appear late in the growing season, on total yield and fruit size during the latter part of the season.

Seeds of fresh-market tomatoes 'Sunny' and 'Pik-Rite' were started in the greenhouse in 72-cell flats (cell size 4 × 4 × 6 cm) filled with Jiffy Mix Plus (Jiffy Products, Chicago), a mixture of 50% peat and 50% (w/w) horticultural grade vermiculite supplemented with nutrients, lime, and Mg. The starting dates for early and optimum planting dates were 19 and 29 Mar. 1990, respectively. The seedlings were maintained for 5 weeks in the greenhouse, 1 week in the cold frame, and field-planted on 30 Apr. and 10 May for early and optimum planting dates, respectively. The field experiments were conducted on the farm of Beltsville Agricultural Research Center, Beltsville, Md., on a Keyport fine sandy loam, a clayey mixed mesic Ultisol soil with 2% slope. A preplanting soil test revealed a high level of P (840 $kg \cdot ha^{-1}$), a medium level of K (128 $kg \cdot ha^{-1}$), and a pH of 7.1. Fertilizer was broadcasted before planting at the rate of 45 $kg \cdot ha^{-1}$ for each of the N, P, and K, and disked into the top 0.2 m of soil. This application comprised ≈50% of the fertilizer applied during the growing season. The remaining 50% was applied in the form of soluble fertilizer through the trickle irrigation system at weekly rates of 0.5, 0.8, and 1.7 $kg \cdot ha^{-1}$ for N, P, and K, respectively. The first application through the trickle irrigation system was made on 18 June, at which time the early fruits on the plant were ≈1 cm in diameter. The last application was made on 2 Oct., 1 week before the last harvest.

Seedlings were field-planted into 7-cm-diameter holes as a single row in the center of mulched and unmulched beds (1.2 m wide and 0.15 m high) with one trickle irrigation line (Turbo Tape, San Diego, Calif., 2.5 × 10^{-1} mm thick; 30 cm emitter space; 350 $liters \cdot h^{-1}$ discharge rate/100-m line) in each bed buried 5 cm below the soil surface and 10 cm away from the plants. BPM 1.5 m wide and 2.5 × 10^{-2} mm thick was laid by machine. Trickle irrigation was initiated immediately after transplanting and terminated at the conclusion of the study. Standard cultural and pesticide practices for commercial tomato production, including staking, were followed. Weeds were controlled by a preplant soil-incorporated application of 1.1 kg napropamide *[N,N* -diethyl-2-(1-naphthalenyloxy)propanamide]/ha and 4.7 kg Pebulate *(S* -propyl butylethylcarbamothioate)/ha. Three postemergence applications of 0.65 kg paraquat (1-1'-dimethyl-4-4'-bipyridinium ion)/ha were performed to control weeds in unmulched (control) beds and in furrows between beds of mulched and unmulched treatments. Pest control consisted of four applications of oxamyl *(N-N* -diamethyl- α–methylcarbamoyl-oxyimino- α -(methylthio)acetamide at 0.9 $liter \cdot ha^{-1}$ and two applications of azinphos-methyl *(S* -(3,4-dihydro-4-oxobenzo{d}-{-1,2,2}-triazin-3-ylmethyl) *O-O* -dimethylphosphorodithioate at 0.67 $kg \cdot ha^{-1}$.

For determining the effect of BPM on total yield and early production, we used a completely randomized factorial design. The factors were mulch treatment (mulch and no mulch), cultivars (Sunny and Pik-Rite), and planting dates (early and optimum). There were eight replicates per treatment for each planting date. For determining the effect of sink reduction on yield and fruit weight, an additional factor, flowers left or removed, was added. There were four randomly assigned replicates per treatment for each planting date. Each replicate consisted of 20 plants spaced 0.6 m within the row and 1.6 m between rows. Means that were significantly different according to an F test were separated by LSD ($\alpha = 0.05$).

The effects of BPM on total yield were established by harvesting once a week at the breaker to firm-ripe stage and weighing the fruits. Harvests extended from 3 July-10 Oct. The effect of BPM on early fruiting was established on fruits of the first three harvests of each cultivar in each of the two planting dates. The effects of sink reduction (flower removal) on yield and fruit weight during the last 5 weeks of the harvest period were determined by removing all flowers that appeared between 5 Sept. and 10 Oct., from four replicates of each planting date and keeping the flowers on the other four replicates in each treatment. During this period, five harvests were made. Fruits from each harvest were counted and weighed, and the data were analyzed to determine the effect of sink reduction on yield and fruit weight of each harvest separately and of the five harvests combined.

Total yields of 'Sunny' and 'Pik-Rite' in the unmulched (control) treatment over the two planting dates averaged 46.0 and 40.0 $t \cdot ha^{-1}$, respectively (Table 1). Total yields of the two cultivars were 95% higher in the BPM than in the unmulched treatment, and these highly significant *(P* < 0.01) differences appeared in both early and optimum planting dates. Total yields of the early and optimum planting dates in the mulch treatment were similar in 'Sunny' but different in 'Pik-Rite', in which the yield of the early planting date was significantly higher than that of the optimum planting date. In the unmulched treatments, no differences between the early and optimum planting dates were observed in 'Pik-Rite'.

There were no differences in total yield of 'Sunny' and 'Pik-Rite' when the mulch treatments of the early planting date were compared, nor were there differences between the unmulched treatments of the early planting date. In contrast, 'Sunny' produced a significantly higher yield than 'Pik-Rite' on the optimum planting date in both mulched and unmulched treatments.

Our results on the effect of BPM on total yield are similar to those reported by Bhella (1988). Other published data on increases in total yield varied greatly. In one report (Taber, 1983), no increase in yield under BPM was observed. In other reports, increases in yield under BPM ranged from 13% (Wien and Minotti, 1987) to 69% (Ashworth and Harrison, 1983). Such yield differences in response to BPM have been attributed to environmental factors such as soil temperature and moisture (Taber, 1983).

Our results show that, in both 'Sunny' and 'Pik-Rite', there was an increase in total yield under BPM over the control in both early and optimum planting dates (Table 1). Plants on both planting dates received similar cultural practices, particularly with respect to fertilizer and water applications. We made no attempt to determine differences among treatments with regard to evaporative loss of water applied to the plots. The main observed variable was the temperature. Average minimum temperatures during April were 4.3C lower than those during May (data not shown), and this low temperature would have more adverse effects on growth of plants of the early than the optimum planting date. Hence, it is likely that the increase in total yield under BPM on the early planting date could, in part, be attributed to higher soil temperature under BPM. Higher soil temperatures under BPM than in unmulched treatments have been reported (Bhella and Kwolek, 1984; Taber, 1983).

Variability in total yields of fresh-market tomato cultivars grown under BPM has been attributed to several factors, such as soil type and fertility, planting date, and cultural practices. Total yields ranged from 40.0 (Perry and Sanders, 1986) to 72.8 $t \cdot ha^{-1}$ (Wien and Minotti, 1987). Major differences in total yield from year to year were also reported (Decoteau et al., 1989). The high total yields we obtained using BPM (87 $t \cdot ha^{-1}$) are attributed to selecting high-yielding fresh-market cultivars, growing them under BPM, and using trickle irrigation and multiple applications of fertilizer, both of which are known to increase yields (Bhella, 1988; Lin et al., 1983).

Black polyethylene mulch had no effect on early fruiting (first three harvests) of 'Sunny' in either planting date (Table 1). In contrast, BPM significantly increased early fruiting in 'Pik-Rite' in both planting dates, leading to a significant mulch × cultivar interaction (Table 2) and also a significant mulch × date interaction at $P = 0.10$. There was no effect of planting date on early fruiting by 'Sunny' or 'Pik-Rite' in the mulch treatments. The reverse was observed in the unmulched treatments in which the early planting date for both cultivars exhibited significantly higher early fruiting than the optimum planting date.

The increase in early fruiting due to BPM was significantly greater in 'Pik-Rite' than in 'Sunny' over both planting dates. In contrast, early fruiting was similar for both cultivars in the control treatments on either planting date. Since the increase in early fruiting due to BPM was significant in 'Pik-Rite' but not in 'Sunny', and since the greatest difference in early fruiting between mulched and unmulched treatments was observed in the optimum planting date of 'Pik-Rite' (Table l), BPM likely affects early fruiting by increasing the efficiency of water and fertilize use. Black and Greb (1962) presented evidence in support of an increased efficiency of water and fertilizer use by to**mato** plants under BPM.

Whereas significant increases in total yields of field-grown fresh-market tomatoes grown under BPM have been established, the increase in early fruiting under BPM is not consistent. Sweeney et al. (1987) reported a 33% increase in early fruiting of tomatoes under BPM, and Wien and Minotti (1987) found an increase only in 1 of 2 years. Under our experimental conditions, only one of the two tested cultivars responded to BPM by producing a significantly higher early fruiting than the control. The effect of BPM was greater for the optimum planting date than the early planting date.

Increases in yield and fruit weight in response to sink reduction may be critically affected by the timing of the treatment. It is possible that the sink reduction treatment in our experiments was not initiated early enough in the season to produce an effect. This treatment is most effective in increasing fruit size in fruit trees bearing a heavy fruit load when it is done early in the season (Edgerton, 1973). Another possibility may relate to the location of the eliminated sinks on the plant. Flowers that were eliminated were predominately on the tips of new growth where leaves were not fully expanded and, consequently, did not contribute much to the production of synthates. In contrast, developing fruits that are potential sinks and would benefit from sink reduction are lower on the branches, where the leaves are fully expanded and serve as active synthate production centers. Most of the synthates that end up in these sinks likely originate from the mature leaves in their vicinity, and a very insignificant amount of synthates may come from the expanding leaves of the growing tips. In a situation like this, one would anticipate very little effect of flower removal from the growing tips on yield and fruit weight of fruits located in the lower portions of the plant.

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