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Yields of Tomato Phenotypes Modified by Planting Density, Mulch, and Row Covers

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Abstract. **Bare ground (BG), black polyethylene mulch (ML), and polyester row covers with mulch (MRC), combined with three planting densities, provided increasing levels of cropping intensity to study phenotypic response. Four tomato (*Lycopersicon esculentum* Mill) phenotypes, 'Sub Arctic Maxi' (SAM), 'New Yorker' (NY), UNH-328 (328), and 'Westover' (WVR) represented combinations of small and large plant size and early and late maturity. Early and total yield responses to planting density were linear whether in ML, MRC, or BG treatments, and each phenotype also showed predominantly linear yield increases with increasing density. These linear increases were enhanced in SAM by ML and MRC, but the same mulch and row cover treatments tended to reduce the density response in other phenotypes. The difference was believed to relate to flowering pattern and time relative to vegetative development. Within MRC, compact plants were the most responsive to density in total, but not in early, yield. The predominant effect of ML and MRC was to improve earliness, with each treatment contributing an increment increase in early yield. However, the performance of one phenotype (328) was unchanged by ML or MRC, perhaps reflecting inherent stability.**

Within erratic or unfavorable climates, productivity of plants, particularly those adapted to warm temperatures, has been enhanced by altering the micro-environment. Row covers improve early and total yields of several vegetable crops by increasing soil and air temperatures under the cover, thereby accelerating early growth (1, 6, 12). Black polyethylene mulch may increase early and total yields of tomatoes by modifying soil temperature, moisture retention, nutrient availability, and by suppressing weeds (5, 10, 13). In northern areas, the slight insulative effect of row covers (from 1° to 3°C) may be sufficient to allow planting 2 to 3 weeks before the normal planting date (7). Although plastic mulch and row covers add to production costs, economic efficiency of their use might be improved by increasing planting density. Increases in density generally increase both early and total yields per hectare (3, 4, 8, 9, 14), even though interplant competition for nutrients, moisture, and light may decrease per-plant performance. In some environments, disease and insect pressure may increase as density increases.

Yields of tomatoes grown under row covers have been inconsistent. Flower abortion within overheated row covers or increased competition due to early stimulation of vegetative growth may account for this inconsistency. Competition affects individual plant yield most when it occurs early in the growing season, and competition occurs in high planting densities earlier than in normal spacings (2).

Although the effects of planting density on tomatoes differing in plant growth habit have been reported (4, 9), the extent to which specific genetic traits are important for successful production under row covers has not been examined. The objective of this research was to determine a) competitive effects of increased planting density within increasingly intensive production environments, and b) the possible influence of plant habit and earliness on productivity within these environments.

The experimental design was a split-plot with six replications. The main plots were unmulched control (BG), mulched (ML), and mulched + row cover (MRC). Three planting densities and four phenotypes constituted the split-plots. Each phenotype was seeded in Speedling trays (128 size) in the greenhouse on 10 Apr. for the MRC treatment and field-planted on 16 May. Phenotypes for the remaining treatments were seeded 24 Apr. and transplanted 26 May to avoid frost damage. The MRC treatment therefore reflected both the modified environment under the cover and the early planting date. The rows were placed in beds 1.8 m apart on center and 3.6 m long. Guard plants were placed between consecutive plots, between adjacent main plots, and around the entire trial.

The three planting densities included: a) a single row (control) of plants 0.6 m apart (8963 plants/ha); b) a diamond design constructed of three rows 0.3 m apart in beds, with plants in each row spaced at 1.2 m intervals [the center row plants alternated with those in the outer rows to form the end-points of the diamond (13,444 plants/ha)]; and c) a twin row, with rows and plants within rows spaced 0.6 m apart (17,926 plants/ha), but with plants of one row placed midway between plants of the adjacent row. The areas per plant for each planting density were 1.1, 0.83, and 0.55 m^2, respectively. Standard cultural and pest control systems were used. The field was irrigated when necessary to ensure that the experiment received at least 2.5 cm of water each week until harvest began.

Four tomato phenotypes represented contrasting combinations of earliness and plant habit. The early maturing phenotypes were 'Sub-Arctic Maxi' (SAM), a very early small plant, with mean fruit size of 60 g, and 'New

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Yorker' (NY), with a large plant relative to SAM and a mean fruit size of 90 to 100 g. The late-maturing phenotypes were 'Westover' (WVR), with the largest plant size of the four tested and an average fruit size of 170 g, and UNH 328-3 (328), with a compact plant larger than SAM but smaller and more erect than NY and a mean fruit size similar to that of WVR. Prior to planting, the experimental area received 1.1 $t \cdot ha^{-1}$ of granular fertilizer (5.3N–6.6P–12.5K) and *N,N*-dimethyl-phenylbenzeneacetamide (diphenamid 50W) was applied 1 week after the final planting date for general weed control. Black polyethylene mulch (1.2 m wide × 28 μm thick) was applied to all ML and MRC plots prior to the first transplanting date. Following early field planting, spunbonded polyester row covers (Reemay, DuPont) were placed, without supporting hoops, directly over the plants in appropriate treatment plots.

The row covers were removed 14 June, when ambient air temperatures > 30°C were recorded. Weekly harvests began 21 July, continued to 8 Sept., and included data for early yield (the first five harvests), total yield, marketable early and total yields, and fruit size. The marketable yield data were similar to those of early and total yields and are not reported. All data were analyzed using the analysis of variance and GLM procedures of SAS (SAS Institute, Cary, N.C.).

Soil and air temperatures and soil moisture were recorded in two replicates, using a digital temperature probe and a Bouyoucos system, respectively. Air temperature was measured at 15 cm above the ground, adjacent to a plant located at random within the plot. Soil temperature was measured at a 5-cm depth at the same location. The soil moisture blocks were placed at random in each plot at a 15-cm depth.

Differences among phenotypes were significant for both total and early yields (Tables 1 and 2). Because WVR was very late-maturing and early yield data were not sufficient to provide reliable comparisons, only total yield results are reported for this phenotype.

Mulching treatment main effects were highly significant for both early fruit number and early fruit weight (Table 1). Total fruit number was increased by ML and MRC, but total fruit weights from these treatments were not statistically different from BG (Table 2). Among BG, ML, and MRC treatments, the effects of plant density were consistent, each treatment showing a linear yield increase with increasing density (data not reported). Orthogonal comparisons and trends within each phenotype also showed a strong linear increase in both early and total yield (number and weight) as planting density increased. The use of plastic increased early yield of early phenotypes substantially over the BG control (Table 1), and the MRC treatment was superior to ML for these phenotypes. Only SAM showed increased total yield (number of fruit) in ML and MRC (Table 2).

Comparisons among phenotypes within MRC suggest that compact plant types (SAM,

Table 1. Effects of planting density, mulch, and row covers on early yield of three tomato phenotypes.

Treatment[z]	Phenotype			Mean
	SAM	NY	328	
	Early fruit no. (1000 fruit/ha)			
Density (m^2/plant)				
1.10	381	157	50	196
0.83	480	201	65	249
0.55	681	247	85	338
Mulching				
BG	378	147	64	196
ML	407	151	65	208
MRC	739	306	73	372
Mean	508 a[y]	210 b	67 c	259
Significance[x]				
Density	L**	L**	L**	
Mulching				
BG vs. (ML + MRC)	**	**	NS	
ML vs. MRC	**	**	NS	
	Early fruit wt. ($t \cdot ha^{-1}$)			
Density (m^2/plant)				
1.10	24	17	10	17
0.83	30	20	12	21
0.55	38	25	16	26
Mulching				
BG	25	16	13	18
ML	27	17	12	19
MRC	40	29	12	27
Mean	31 a	21 b	12 c	21
Significance[x]				
Density	L**	L**	L**	
Mulching				
BG vs. (ML + MRC)	**	**	NS	
ML vs. MRC	**	**	NS	

[z]BG = unmulched control; ML = mulched; MRC = mulch + row cover.
[y]Means separated by Duncan's multiple range test, $P = 5\%$.
[x]L = linear, **,NS Significant at $P = 1\%$ and not significant, respectively.

Table 2. Effects of planting density, mulch, and row covers on total yield of four tomato phenotypes

Treatment[z]	Phenotype				Mean
	SAM	NY	328	WVR	
	Total fruit no. (1000 fruit/ha)				
Density (m^2/plant)					
1.10	617	506	336	334	448
0.83	783	621	393	689	622
0.55	959	689	527	468	661
Mulching					
BG	659	534	386	256	491
ML	736	622	452	401	552
MRC	965	657	418	426	620
Mean	787 a[y]	604 b	419 c	361 c	555
Significance[x]					
Density	L**	L**	L**Q*	L**	
Mulching					
BG vs. (ML + MRC)	*	NS	NS	NS	
ML vs. MRC	*	NS	NS	NS	
	Total fruit wt. ($t \cdot ha^{-1}$)				
Density (m^2/plant)					
1.10	36	50	53	55	49
0.83	46	60	60	65	58
0.55	54	65	77	70	67
Mulching					
BG	42	55	63	59	55
ML	45	62	65	63	59
MRC	49	59	61	68	59
Mean	45 a	58 b	63 c	61 c	58
Significance[x]					
Density	L**	L**	L**	L**	
Mulching					
BG vs. (ML + MRC)	NS	NS	NS	NS	
ML vs. MRC	NS	NS	NS	NS	

[z]BG = unmulched control; ML = mulched; MRC = mulch + row cover.
[y]Means separated by Duncan's multiple range test, $P = 5\%$.
[x]L = linear, Q = quadratic, *,**,NS significant at $P = 5\%$ or 1% and not significant, respectively.

328) were better-adapted to those conditions than were larger-vined phenotypes (Table 3), especially in total yield. The relative yield gains of SAM in MRC exceeded all other phenotypes as planting density increased (Table 3). Most of the other phenotypes showed a diminished return from MRC at high densities. The different response of SAM compared with other phenotypes might be explained, at least in part, by earliness, flowering habit, and plant size. SAM would likely be affected less than the other phenotypes by competition because of its relatively small plant size and because the concentrated, early flowering allowed fruit set and subsequent development to occur predominantly before foliage and root systems merged within the beds. Although ML and MRC accelerated growth and flowering in SAM, as in other phenotypes, a substantial fruit load had developed before competition began. The remaining phenotypes were larger in plant size than SAM, and flowering was more dispersed over time. As a consequence, the stimulation of vegetative growth by MRC likely accelerated the onset of competition within those phenotypes. The effect of this stimulation was most evident for total yield. Nevertheless, even though gains in total yield were diminished in these phenotypes by row covers as planting density increased, the substantial early yield improvement was a major asset.

WVR, with the largest plant size, declined in total weight on bare ground plots at the highest planting density (data not shown). This probable consequence of competition was ameliorated by ML and MRC. We had expected that the early planting in MRC plots might have increased competition among large plants more than in BG plots. However, soil moisture, especially during fruit set and development, was retained longer under ML and MRC than in BG plots, perhaps delaying the competitive effects of early growth in the MRC treatment.

Phenotype 328 was unique. Its total fruit number and weight and early fruit weight showed little or no response to ML or MRC (Table 4). In view of the significant improvement in early yield of other phenotypes and the early planting date under the row covers, the apparent stability of 328 was striking. Modification of microclimate through spacing and row treatments and perhaps other changes in cultural techniques might provide a convenient means for testing stability of certain traits or for evaluating breeding lines for stability, although a broad range of phenotypes, some known to be stable, should be used to test usefulness of such a system.

When yields increased in response to any treatment (density ML or MRC), the relative gain in number of fruit was often greater than the gain in fruit weight, a response previously reported as planting density was increased (4). This tendency was more evident in early fruit size data than in total yield size (Table 5). Plant spacing was more important in determining fruit size than was mulching treatment, and early fruit size was affected more than was total fruit size. The reduction in mean early fruit size within the combined high-density MRC treatment was 23%, but only 4% for total fruit size.

Table 3. Percentage change in yield in each mulching treatment due to density[z].

Phenotype	Change in yield (%)[z] — Mulching treatment: BG	ML	MRC
		Total fruit no.	
SAM	40	42	80
NY	51	36	25
328	69	48	58
WVR	41	60	24
		Total fruit wt.	
SAM	34	56	54
NY	43	28	22
328	49	38	49
WVR	21	44	16
		Early fruit no.	
SAM	61	78	92
NY	65	91	39
328	87	114	29
		Early fruit wt.	
SAM	49	79	58
NY	67	72	31
328	52	103	35

[z]Gain from lowest to highest planting density in each plastic treatment.

Table 4. Percentage change in yield due to row cover and mulch within each planting density.

Phenotype	Change in yield (%)[z] — Spacing per plant (m^2): 1.10	0.83	0.55
		Total fruit no.	
SAM	19	64	53
NY	43	15	16
328	9	3	2
WVR	40	6	8
		Total fruit wt.	
SAM	8	21	24
NY	23	1	5
328	1	−7	<1
WVR	21	9	16
		Early fruit no.	
SAM	79	102	113
NY	127	115	92
328	40	26	4
		Early fruit wt.	
SAM	54	55	64
NY	100	87	57
328	4	−10	−8

[z]Difference between MRC and BG.

Table 5. Average fruit size within each row treatment and planting density.

Mulch treatment	Space per plant (m^2)	Total yield fruit size: Mean (g)	Index[z]	Early yield fruit size: Mean (g)	Index
BG	1.10	114 ± 10[y]	100	159 ± 15	100
	0.83	126 ± 10	110	153 ± 15	96
	0.55	126 ± 9	110	144 ± 13	91
ML	1.10	117 ± 9	103	152 ± 14	96
	0.83	127 ± 14	111	149 ± 14	94
	0.55	118 ± 8	104	148 ± 13	90
MRC	1.10	120 ± 11	105	135 ± 14	85
	0.83	109 ± 9	96	130 ± 14	82
	0.55	110 ± 10	96	123 ± 12	77
Mean	1.10	121	106	149	94
	0.83	121	106	144	91
	0.55	112	98	137	86
Significance					
Spacing, linear		*		**	
BG vs. (ML + MRC)		NS		NS	
ML vs. MRC		NS		*	

[z]Indexed to the control (BG, 1.1 m^2/plant)
[y]Mean ± SE
NS,*,**Not significant or trend or comparison significant at $P = 5\%$ or 1%, respectively.

Porter and Etzel (11) concluded that peppers could be grown on plastic mulch at densities greater than normally used. Based on the responses observed in this trial, it is clear that ML and MRC can enhance number of early tomato fruit and that increased planting densities will produce yields per hectare higher than conventional single row plantings at in-row spacings of 0.6 to 0.9 m. However, certain cultivars may be more useful for such cultural systems than others. The performance of compact phenotypes under row covers seemed to be affected less by competitive spacings than that of large plants. Compact plants therefore would be preferred in high populations. A wide range of phenotypes may be suitable for row cover environments at conventional spacings. In general, however, early cultivars would be preferred for a row cover cultural system, accentuating the early advantage of the covers. There was no evidence in this trial that flower abortion increased within row covers, in spite of high air temperatures in the week to 10 days prior to row cover removal. SAM and NY were both flowering during that period, and early yields of both increased as a result of covers. Genetically stable lines, as yield data suggest 328 might be, would offer no economic advantage in enhanced environments.

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Economic Evaluation of Different Cultural Systems for Muskmelon Production

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Abstract. **Sixteen management systems for early muskmelon production were compared for marketable yield, gross revenue, treatment cost, net economic value, and benefit-cost index. Black plastic mulch and/or transplants increased yields, gross return, and net economic value over a conventional practice of bare soil, direct-seeded production. Row covers did not increase yields or gross returns. When net economic value and benefit cost criteria were evaluated, yield maximization was not necessarily the best strategy. Instead, careful analysis should be given to added costs of production practices and the added revenue these practices will generate.**

Growers perceive early vegetable production as one key to market access and higher vegetable prices. Researchers have investigated the use of plastic mulches, transplants, and row covers as techniques to increase early vegetable production and improve yields (1–5). Successful adoption of these technologies requires reliable answers to the questions: Will the practice result in earlier harvesting? Is the market price expected to be higher at an earlier harvest period? Are there sufficient additional revenues generated by the practice to cover the additional cost of adopting the practice? This study was initiated to provide on-farm information to compare alternative stand establishment, plastic mulch, and row cover production practices for muskmelons.

A 2 × 2 × 4 factorial experiment was conducted giving 16 management systems. Treatments were arranged in a split-plot design with four replicates. The main plots were four combinations of either black plastic mulch or bare soil and direct seeding or transplanting. Subplots consisted of four row cover treatments: 1) perforated clear polyethylene (PC) 1.8 m wide and 0.51 mm thick, with 1.9 cm-diameter holes spaced 5 cm apart with 7% of the surface area in holes (Agplast Co., Rexdale, Ont. Canada); 2) slitted clear polyethylene (SC) 1.7 m wide and 0.71 mm thick, with 12.7-cm slits spaced 1.27 cm apart on either side of the row cover (Ken-Bar Inc., Reading, Mass.); 3) spunbonded polyester nonwoven fabric (SB) 1.7 m wide and 0.97 mm thick (Reemay, trademark of DuPont Co, Wilmington, Dela.); and 4) a control with no row cover (NC). Plots were 1.7 m wide and 4.6 m long.

This study was placed on a farm in the northwestern Piedmont region of North Carolina on a sandy loam soil with a pH of 6.0. Fertilizer was broadcast just prior to fumigation at the rate of 112N–20P–41K ($kg\cdot ha^{-1}$). On 19 Apr. 1984, all plots were fumigated with 66% methyl bromide/33% chloropicrin at a rate of 136 $kg\cdot ha^{-1}$ and covered with embossed black plastic mulch (BP) 0.38 mm thick. All experimental plots were fumigated to control weeds and nematodes, since a preseason assay revealed possible nematode infestation. Before planting, BP was removed from plots designated as "no plastic" (NP) treatments.

All direct seeding (DS) and transplanting (TP) of 'Superstar' muskmelons was done on 7 May. Transplants, from seeds sown on 12 Mar. in 3.2-cm square plastic cells filled with peat-lite mix, were spaced 45 cm apart in the rows in the field. There were 10 plants per plot. Seeds were sown at the rate of 4.5 per meter of row length. Seedlings were thinned to 45 cm apart in the rows on 14 May, leaving 10 plants per plot. Row covers (RC) were applied immediately after thinning because wet soil made earlier applications impractical. Four wire hoops per plot were used to support PC and SC, whereas SB was not supported. The time needed to apply the row covers by hand was recorded, and application costs were estimated using a labor wage rate of $4.50/hr.

Row covers were removed and plants were counted 5 weeks after planting. Runner number and length were noted at this time. Harvesting began 68 days after planting and lasted for 27 days. Fruit were harvested three times per week and then counted, weighed, and classified as marketable grade or cull according to USDA grade standards for muskmelon (6). The harvesting and packing rate was observed to be 100 melons/hr. Using a labor wage rate figure of $4.50/hr, cost of harvesting and packing then was calculated to be $0.045/melon.

During the harvest period, wholesale market prices were obtained from the *Columbia, S.C., Market News Report* (7) weekly, and individual harvests were aggregated into weekly totals. Market News prices were adjusted downward by $0.06 per melon in or-

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