Maturity of Fresh-market Sweet Corn with Direct-seeded Plants, Transplants, Clear Plastic Mulch, and Rowcover Combinations

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SUMMARY. Sweet corn (*Zea mays* L.) growers in the upper midwestern U.S. have used clear plastic mulch to improve early yield and advance crop maturity. Results of this practice have been inconsistent because of early season temperature variability and inadequate information on cultivar adaptation. Our objective was to improve the performance consistency by investigating earliness techniques with the early, sugary-enhancer (*se*) cultivar Temptation planted at two sites. Treatments were bare soil or clear plastic mulch, rowcovers or none, and direct-seeded or transplanted plants. Transplants were produced in the greenhouse in either 50-cell plastic trays or peat pot strips, 2.3 inches × 4.0 inches deep (6 × 10 cm) and were evaluated according to transplant age and cell size. In the cold springs of 1996 and 1997, the use of clear plastic mulch shortened maturity of sweet corn by 1 and 10 days, respectively, for the silt loam site; but no maturity advantage was observed for the loamy sand site. Clear plastic raised the minimum soil temperature by 3.8 to

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4.0 °F (2.1 to 2.2 °C) at both sites. The 2-week-old 50-cell tray transplants matured 6 days earlier than the peat pot strip transplants or direct seeded at both locations in 1997. Marketable yield from the transplants was inconsistent by location and year. Four-week-old transplants did not withstand field stress and performed poorly regardless of type of container. Ear quality as indicated by row number, ear diameter, ear length, and tipfill was lowest with transplants.

Sweet corn is a warm-season crop adapted to temperate climates. It is produced as a cash crop in the midwestern United States for either the fresh or processing market. The cool climatic conditions and short growing season in the upper midwestern U.S. limit the production season. To facilitate early sweet corn production, soil temperature should be raised to 54 °F (12.2 °C), the minimum necessary for extensive root growth and nutrient absorption (Wilcox and Pfeiffer, 1990).

Low soil and air temperatures impede sweet corn seed germination and early growth. Dinkel (1966) showed that clear plastic mulch can raise soil temperature and advance germination of early planted sweet corn sufficiently enough to improve the number of marketable ears. Hopen (1965) found that clear plastic mulch improved emergence by 81% 11 d after planting. Silk formation and harvesting dates are advanced on average by 6 to 14 d with the use of either clear plastic mulch or rowcovers (Bible, 1972; Hopen, 1965; Kretschmer, 1979).

Rowcovers with plastic mulches have been used to modify the growing environment for vegetables (Splittstoesser and Brown, 1991). Polyethylene rowcovers with perforated slits for ventilation have been used successfully in the production of vegetables such as watermelon (*Citrullus vulgaris* Thumb.) and muskmelon (*Cucumis melo* L.) (Taber, 1993; Wilson et al., 1987). In a limited study in Oregon, Mansour (1984) found that sweet corn grown under rowcovers matured 17 d earlier than bare ground plantings, yielding a net return of $688 to $3198 / acre ($279 to $1295 / ha) higher than sweet corn produced on bare soil.

Some vegetables, including sweet corn, are regarded as difficult to transplant because of a greater shoot-to-root ratio, a lower rate of root regeneration after transplanting, and lower intake of nutrients by the older roots of transplanted seedlings compared with direct-seeded plants (Loomis, 1924). Ricketson and Thorpe (1987), working in eastern Canada, observed a 7 to 12 d earlier maturity of sweet corn transplants compared with direct-seeded plants. In addition, Ledent et al. (1981) reported a harvest advantage of 10 to 15 d when 2-week-old transplants were compared with direct-seeded plants. However, transplanting sweet corn has not been widely adopted for a number of reasons, such as high cost, lack of consistent earliness compared to direct-seeded methods, and decreased ear length (Waters et al., 1990; Wyatt and Akridge, 1993). Waters et al. (1990) reported a slower growth rate and lower yield of sweet corn transplants that were more than 3 weeks old at the time of transplanting. These effects were attributed to greater root damage of the older seedlings with a subsequent increase in plant stress.

Because growers would benefit from premium market prices early in the season, information on the performance of direct-seeded or transplanted sweet corn planted under clear plastic mulch, rowcovers, or a combination of clear plastic mulch and rowcovers will be important. The objectives of this study were to compare soil temperature changes, growth, yield, and ear quality of sweet corn grown as either direct-seeded plants or transplants under clear plastic mulch, rowcovers, or a combination of rowcover and clear plastic mulch.

Materials and methods

Location. Trials with ‘Temptation’ sweet corn, a *se* type, were conducted in 1996 and 1997 at the Horticulture Research Station in central Iowa, and at the Muscatine Island Research Farm along the Mississippi river in eastern Iowa in 1997. The soil in central Iowa was a well-drained silt loam (fine-loamy, mixed, mesic Typic Hapludolls) with 4.6% organic matter content. The site in eastern Iowa was a well-drained loamy sand soil (sandy, mixed, mesic Entic Hapludolls) with 0.5% organic matter content. At both sites, the previous crop was rye (*Secale cereale L.*), and rye strips were left around the plot area to serve as windbreaks.

Treatments. Treatments consisted of production on bare soil or with clear plastic mulch, rowcovers or no rowcovers, and starting the crop by direct seeding or as transplants. The effect of rowcovers was not tested in 1996. Transplants were evaluated according to age and transplant cell size. Seedlings to be transplanted were grown in the greenhouse for 2 or 4 weeks from seeding. For transplant production, seeds were planted in either shallow, plastic, 50-cell trays (1-inch diameter and 2.3-inch depth (2.5 × 6 cm), or deep, peat pot strips (Jiffy Products of America, Batavia, Ill.) that were 2.3 inches in diameter × 4.0 inches deep (6 × 10 cm). Greenhouse temperature was 68 to 72 °F (20 to 22.2 °C).

Before transplanting, six plants were removed from each plastic tray and peat pot strip for dry mass determination. Treatments were arranged as a factorial within a randomized complete block design. There were four replications per treatment in central Iowa and three at the eastern Iowa site.

Field operations. At the central Iowa location, the trial was seeded both years on 1 May, ≈8 d before the last 25% frost-free date. The eastern Iowa site was seeded on 29 Apr. 1997. Transplanting and direct seeding at both sites were in double row beds with 18 inches between the rows by 12 inches (46 × 30 cm) between plants in row. There were two plants at each row position for a population of 25,448 plants / acre (62,857 plants / ha). There were three beds per plot on 6-ft centers × 25 ft long (1.8 × 7.6 m). Transplanting was done when the seedlings were either 2 or 4 weeks old. The peat pot strips were thoroughly soaked prior to setting in the field. The transplants were set in all plots by hand using a rowel to open the soil. For direct seeding a hand operated corn seeder was used that placed the seeds ≈1.5 inches (3.8 cm) deep. The seeds were planted in the plastic plots by jabbing the seeder through the clear plastic mulch.

Where needed, clear plastic mulch (a photodegradable type) was applied one week before seeding. Both the clear plastic mulch and rowcover materials were thin, linear, low density, polyethylene material. Perforated rowcovers [0.8-inch (2-cm) diameter holes at 4-inch (10-cm) intervals for ventilation] were placed over wire hoops that were spaced ≈5 feet (1.5 m) apart during transplanting. Edges of the rowcovers were pulled tightly over the hoops and buried in the soil to prevent sagging and to give a center height of 14 inches (36 cm). The rowcovers were removed when plants reached the four-leaf stage of growth.

Soil pH and standard fertilization and pest management practices were followed at both locations. Irrigation was applied by overhead sprinkler as needed.

DATA COLLECTION. When seedlings were in the fourth leaf stage of growth, a stand count was made to determine plant survival rate. Silk date on each plot was noted when 50% of the plants in a treatment row had formed silk 1 inch (2.5 cm) long. Maturity date was determined when the ears were large enough to fill the husk tightly to the top, and when the kernels were just beginning the milk stage. At harvest, plant height was measured from the ground to the ear and the ground to the extended tassel. Total number and mass of marketable and unmarketable ears was recorded. Any ear that was misshapen or <5.5 inches (14 cm) long was classified as unmarketable. Ear characteristics such as tipfill, ear length, ear diameter, and kernel row number were determined from the mean of six randomly selected ears per plot per treatment.

In central Iowa, soil and air temperatures were measured for all treatments in two blocks with copper-constantan thermocouples placed 4 inches (10 cm) deep in the soil and 6 inches (15 cm) above the ground, respectively. Temperature was monitored with a CR-10 data logger (Campbell Scientific, Logan, Utah) with a scan rate of 5 min and averaged hourly. In eastern Iowa, soil temperature was measured from 1 to 13 May by using a hand probe placed 4 inches into the soil, at 0800 HR Central Standard Time (CST) for minimum temperature and at 1600 HR CST for maximum temperature. No air temperature measurements were taken in eastern Iowa. Data were analyzed by ANOVA and treatment mean differences determined by Duncan's Multiple range test (PROC GLM; SAS version 6.04).

Results

TEMPERATURE EFFECTS. Clear plastic mulch did not influence either the minimum or maximum air temperature in 1996 and 1997 in central Iowa. Average ambient air temperature for May 1996 and 1997 was 5 and 7 °F (2.8 and 3.9 °C) below normal, respectively. For May 1997, there were 6 d of light frost. However, the perforated rowcover increased maximum air temperature in central Iowa 30 °F (–1.1 °C) ($p = 0.05$) in 1997, compared with no rowcover treatment (data not presented). Minimum air temperature was not affected by rowcover.

Mean minimum and maximum soil temperatures were influenced by both plastic mulch and rowcover in central and eastern Iowa (Table 1). The eastern Iowa loamy sand site was 3.6 °F (2.0 °C) warmer than the silt loam soil of central Iowa. At the eastern site, clear plastic mulch increased the minimum soil temperature 3.8 °F (2.1 °C) compared with the bare ground treatment. Clear plastic mulch did not alter minimum soil temperature in central Iowa either year. However, in 1997 the rowcover increased the minimum soil temperature 4.0 °F (2.2 °C). There was no interaction between mulch type and rowcover for minimum soil temperature. The magnitude of the difference in minimum soil temperature among treatments increased with a decrease in bare soil temperature.

Clear plastic mulch had no effect on maximum soil temperature in 1996 in central Iowa and in eastern Iowa in 1997, but it increased the maximum soil temperature by 7.6 °F (4.2 °C) in central Iowa compared with the bare soil in 1997. Rowcover raised maximum soil temperature at both sites by 4.5 to 6.5 °F (2.5 to 3.6 °C) (Table 1). There was no interaction between mulch type for maximum soil temperature.

GROWTH, MATURITY, AND YIELD IN CENTRAL IOWA. In 1996, clear plastic mulch advanced market maturity by 1 d for direct-seeded plants, while the 2-week-old transplants matured 5 d earlier compared with the direct-seeded clear plastic treatment (Table 2). The larger volume peat pot strip produced no maturity advantage over the shallow 50-cell tray, both harvested in 79 d. Transplant age affected maturity only where the 50-cell plastic tray containers were used (data not shown for transplant age). The 4-week-old transplants matured 3 d earlier than the 2-week-old transplants The combination of clear plastic mulch and 4-week-old transplants produced in 50-cell trays resulted in an earlier maturity of 9 d compared with direct seeding on bare soil. However, these 4-week-old transplants had <50% survival because of harsh, cold conditions and were eliminated from further study.

Plant stand of the direct-seeded treatments was similar at harvest because the plots were over seeded and thinned to a final stand of two plants per position at the four-leaf stage of growth. There was no effect of clear plastic on marketable yield, but marketable yield from transplants was 293 dozen / acre (8,685 ears / ha) less than the direct-seeded treatments. Ear length was 15% longer (7.1 inches (18 cm) versus 6.2 inches (16 cm)) for plants in the direct-seeded, bare soil treatment compared with other treatments in 1996 (Table 2). Other measured ear characteristics such as ear mass, kernel row number, and tipfill were not affected by the treatments (not all data shown).

In 1997 in central Iowa, direct-seeded sweet corn under clear plastic

Table 1. Mean minimum and maximum soil temperature at 4-inch (10-cm) depth from 6 to 20 May 1997 in central Iowa and 1 to 13 May in eastern Iowa. Data are means of two replicate measurements.

	Soil temp (°F)[z]					
	Minimum			Maximum		
Soil	Central Iowa		Eastern Iowa	Central Iowa		Eastern Iowa
cover	1996	1997	1997	1996	1997	1997
Bare soil	54.5	45.5 b[y]	49.1 b	67.3	68.7 c	73.0 b
Rowcover	---[x]	50.4 a	52.2 a	---	79.0 a	88.3 a
Clear plastic mulch	56.5	47.3 b	52.9 a	69.1	76.3 b	82.0 b

[z]Degrees Celcius = 5 / 9(°F – 32).
[y]Mean separation within the column the column was according to Duncan's multiple range test at $p = 0.05$.
[x]Rowcover was not tested in 1996.

Table 2. Effect of clear plastic mulch (CPL), rowcover, transplants, and transplant cell type on 'Temptation' sweet corn establishment, marketable yield, and ear quality in central Iowa in 1996 and 1997.

Treatment	Plant stand (%)	Days to		Yield (dozen/acre)[z]	Kernel (rows/ear)	Ear length (inches)[y]
		50% Silk	Harvest			
			1996			
Direct seeded						
Bare soil (BS)	97.7	69 a[x]	85 a	1544 ab	15.5	7.1 a
CPL	98.6	66 b	84 b	1732 a	15.6	6.1 b
Transplants + CPL						
2 weeks + 50-cell tray	95.5	63 c	79 c	1369 cb	16.0	6.4 b
2 weeks + peat pot	96.3	68 a	79 c	1320 c	16.1	6.2 b
			1997			
Direct seeded						
BS	100 a	63 a	87 a	1847 a	16.0 a	7.2 a
BS + rowcover	100 a	60 bc	83 b	1405 b	15.5 ab	6.7 b
CPL	100 a	62 ab	77 c	1502 b	15.3 ab	6.7 b
CPL + rowcover	100 a	58 c	77 c	1211 c	15.7 ab	6.4 cb
Transplants + CPL						
2 weeks + 50-cell tray	64 b	57 c	77 c	793 c	13.7 c	6.3 cb
2 weeks + peat pot	60 b	60 bc	83 b	824 c	14.8 b	6.1 c

[z]1 dozen / acre = 30 ears / ha.
[y]1 inch = 2.54 cm.
[x]Mean separation within years and columns by Duncan's multiple range test at $p = 0.05$.

mulch germinated in 16 d, 3 d earlier than the bare soil treatment (Table 3). Seeds planted on bare soil under rowcover germinated 7 d earlier than those under bare soil alone. The shortest time for germination, 9 d, was obtained with a combination of rowcover and plastic mulch. A higher germination percentage (75%) was observed under clear plastic mulch compared to bare soil (55%).

At maturity, plants under rowcovers had a 2.4-inch (6.1-cm) ear height advantage compared with direct-seeded, bare soil plants (Table 3). Ear and tassel heights were lowest in the 2-week-old peat pot strip transplants. At harvest, plant height from transplants was only 82% that of direct-seeded plants.

Days to 50% silk formation and ear maturity were affected by the ground cover treatments in 1997 in central Iowa. Plants under rowcovers and / or a combination of rowcover and clear plastic mulch silked 3 to 5 d earlier than plants in the bare soil treatments (Table 2). Clear plastic mulch hastened maturity by 10 d compared with bare soil. The addition of a rowcover to clear plastic mulch did not reduce maturity time over that of clear plastic. Although the maturity date for the direct-seeded plants on bare soil was similar for both years, plants under clear plastic mulch were earlier by 7 d in 1997 than in 1996.

Unlike 1996, the longer maturing plants that had been direct seeded on bare soil produced the highest yield in 1997 (Table 2). As in 1996, 4-week-old seedlings performed poorly in 1997 in central Iowa (data not shown). Frost and strong winds affected them more than the 2-week-old transplants, and >75% of the seedlings were killed. The tall seedlings were already stressed when set in the field and they tasseled before the plants were large enough to support an ear. Thus, this treatment was eliminated from further analysis. The 2-week-old transplant seedling stand was reduced by 40%, compared with other treatments, resulting in poor yields. Ear length, ear diameter, and ear weight were greater for the direct-seeded bare ground treatments in 1997 (not all data shown). The lowest ear quality, as measured by ear length and kernel row number, was associated with the transplants (Table 2).

GROWTH, MATURITY, AND YIELD IN EASTERN IOWA. The May 1997 average air temperature was 6.0 °F (3.3 °C) below normal. Although minimum soil temperature was increased 3.8 °F (2.1 °C) by clear plastic mulch (Table 1), there was no decrease in time to harvest maturity (Table 4). Use of a rowcover with bare soil shortened harvest by 1 d. The 2-week-old transplants raised in either 50-cell plastic trays or peat pot strips reduced time to 50% silk forma-

Table 3. Effect of clear plastic mulch, rowcover, transplants, and transplant cell type on germination and growth of 'Temptation' sweet corn seeded and transplanted on 1 May 1997 in central Iowa.

Treatment	Days to Germination	Ht (inches)[z]	
		Ear	Tassel
Direct seeded			
Bare soil	19 a[y]	15.7 bc	70.9 a
Bare soil + rowcover	12 c	18.1 a	67.3 b
Clear plastic mulch	16 b	16.9 b	68.1 ab
Rowcover + clear plastic mulch	9 d	18.1 a	66.5 b
Transplants + clear plastic mulch			
2 weeks + 50-cell tray	---	10.6 d	58.3 d
2 weeks + peat pot	---	9.8 d	54.7 e

[z]Ear and tassel height were measured from the ground at harvest, 1 inch = 2.54 cm.
[y]Mean separation within the column by Duncan's multiple range test at $p = 0.05$.

Table 4. Effect of clear plastic mulch, rowcover, transplants, and transplant cell type on establishment, marketable yield, and ear quality of 'Temptation' sweet corn seeded and transplanted on 29 Apr. 1997 in eastern Iowa.

Treatment	Days to 50% Silk	Days to Harvest	Yield (dozen/acre)[z]	Tassel ht (inches)	Ear length (inches)
Direct seeded					
Bare soil	64 a[x]	79 a	1542 b	70 a	6.5 bc
Bare soil + rowcover	62 b	78 b	1542 b	70 a	6.8 ab
Clear plastic mulch	62 b	79 a	1793 a	70 a	7.0 a
Transplants + clear plastic mulch					
2 weeks + 50-cell tray	53 c	72 c	1914 a	56 b	6.4 c
2 weeks + peat pot	54 c	78 b	1490 b	52 c	6.5 c

[z]1 dozen / acre = 30 ears / ha.
[y]Ear and tassel height were measured from the ground at harvest, 1 inch = 2.54 cm.
[x]Mean separation within the column by Duncan's multiple range test at $p = 0.05$.

tion by 10 to 11 d, compared with plants in the direct-seeded bare soil treatments; and the 2-week-old transplants raised in the 50-cell tray matured 7 d earlier than direct-seeded treatments. Marketable yield was greatest with the clear plastic mulch, either direct-seeded plants or transplants from 50-cell trays. The transplants showed stress as evidenced by reduced plant height and ear length compared with direct-seeded plants on clear plastic (Table 4).

Discussion

Previous research that involved clear plastic mulch with sweet corn reported an increase in soil temperature above the bare soil treatments (Andrew et al., 1976). Our results also show that clear plastic mulch and rowcovers raised soil temperature which resulted in early germination and enhanced maturity of 'Temptation' sweet corn. Results of the experiments confirm the reported modification of soil temperature by clear plastic film around the seed zone (Andrew et al., 1976; Army and Hudspeth, 1960). We observed a greater increase in minimum soil temperature under rowcovers by 4.0 °F (2.2 °C) compared with bare soil treatments.

Rowcovers and clear plastic mulch increase soil temperature by retaining net solar radiation (Decoteau and Friend, 1990; Splittstoesser and Brown, 1991). The efficacy of net radiation retention by rowcovers depends on season and crop type (Pollard et al., 1987). Previous research reported hastened germination, development, and maturity of sweet corn cultivars planted under clear plastic mulch (Andrew et al., 1976; Miller and Burger, 1963; Purser and Comeau, 1989). We observed an earlier (by 5 to 12 d) germination under clear plastic mulch and / or rowcover compared with bare soil treatments. This result reinforces work of Hopen (1965) and Kretschmer (1979). Both reported >90% germination of sweet corn seeds grown under clear plastic mulch compared with that of bare soil treatments. The higher rate of germination under clear plastic could be due to an increase in minimum soil temperature that enhanced physiological changes in the seeds (Kretschmer, 1979).

Our data indicate a greater growth rate and maturity of plants grown under rowcovers and / or clear plastic mulch in central Iowa in 1997. Pollard et al. (1987) attributed the efficiency of rowcovers in enhancing vegetable maturity to a reduced radiant and convectional heat loss. It is possible that the enhanced soil temperature caused the plants to develop better root systems early in the season, which allowed sufficient water and nutrient absorption for optimum growth. But treatment effect on yield was inconsistent by location. Direct-seeded plants on bare soil treatments produced the highest yield in 1997 in central Iowa, perhaps because the larger plants had more biomass and / or leaf surface area for carbohydrate production. But at the eastern Iowa site, plant growth was similar for all treatments; and the clear plastic mulch, with either direct-seeded plants or 50-cell tray transplants, significantly increased yield by 329 dozen / acre (9,752 ears / ha). Generally, the longest maturity treatment, bare soil, resulted in a more attractive, marketable ear as measured by ear length (Table 2). The use of a rowcover with direct-seeded plants reduced yield in central Iowa with no effect on yield in eastern Iowa.

The reduction in yield by use of transplants was a direct result of stand loss. Wyatt and Akridge (1993) associated reduced height of transplants to transplant shock, reduced root growth, and direct loss of leaves at transplanting. The reduction in growth and vigor of the 4-week-old transplants makes them unsuitable for commercial production of sweet corn. The results confirm those reported earlier by Waters et al. (1990). The 2-week-old transplants produced in the 50-cell tray out performed the peat pot strip transplants for earliness and were similar or greater for marketable yield.

The effect of production methods that promote earliness on maturity date and marketable yield of sweet corn cultivars is dependent on the weather and soil type. The most economical practice is the use of a high quality, vigorous cultivar tolerant of cold soils. In this study the use of clear plastic mulch with direct seeding hastened maturity by 10 d, but this response was inconsistent from year to year. In years where a benefit occurs, production under clear plastic mulch may pay the costs in years when it does not. The production techniques are more suitable with new high sugar sweet corn cultivars, which are poorly adapted to low soil temperatures. Rowcovers with direct-seeded plants inconsistently provided an earliness benefit, but consistently reduced marketable yield.

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