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Seed Moisture and Transplant Management Techniques Influence Sweet Corn Stand Establishment, Growth, Development, and Yield

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. *Additional index words.* seed imbibition, maturity, ear height, ear length, ear weight, tip unfill, plant height, cultivar

Abstract. **A series of experiments exploring the effect of seed moisture and transplant management techniques was conducted with *sh2* and *su* sweet corn *(Zea mays* L.). The use of seed and transplants in a progression of developmental stages from dry seed to moistened seed to 14-day-old transplants showed that moistened seed had no impact on plant 'growth and development. Use of transplants generally had little impact beyond decreasing percent survival and plant height. Increasing the age of transplants reduced the time to maturity and harvest. Increasing the size of the transplant container (paper pot) decreased the time to harvest for younger seedings, but had no other effects. Premoistened seed were successfully held at 10C for up to 72 hours without damage following moisturization. Delays in irrigation of up to 2 days after planting moistened seed had no detrimental effects on sweet corn emergence and growth.**

There is general consensus that growers of fresh market sweet corn are interested in the earliest possible maturity for optimal prices. In any location, suboptimal soil and air temperatures limit the earliest possible planting time; consequently, much research has been conducted on seed handling techniques and transplanting systems to shorten the period from planting to harvest.

One of the seed handling techniques employed has been manipulation of seed moisture before planting. Increasing the seed moisture content (via imbibition) before planting has been shown to improve earliness' and uniformity of emergence (Bennett and Waters, 1987a, 1987b), increase postemergent seedling weights (Gubbels, 1975), and decrease susceptibility to chilling injury (Cal and Obendorf, 1972) and mechanical damage (Gatongi, 1982).

A more traditional approach to enhancing earliness has been the use of transplants. Transplanting sweet corn decreased time to harvest by 1 to 3 weeks, depending on the transplant age, in Massachusetts (Miller, 1972) and Tennessee (Wyatt and Mullins, 1989), and by 10 to 15 days in France (Ledent et al., 1981). Effects on yield and mature plant characteristics have varied, depending on age of transplants and time of transplanting. Grain yield responses ranged from being increased by transplanting for mid-season (Bockstaele et al., 1979) and late-season plantings (Lazim, 1985) to being equal to (Pendleton and Egli; 1969) or decreased (Carranza and Vicuna, 1978; Flood-Page, 1976; Wyatt and Mullins, 1989) in comparison to direct-seeding. Transplanting generally produced shorter plants with less dry matter and decreased leaf area (Carranza and Vicuna, 1978; Lazim, 1985; Lendent et al., 1980, 1981; Pendleton and Egli, 1969; Wyatt and Mullins, 1989). Ear length decreased in Massachusetts (Miller, 1972) and Tennessee (Wyatt and Mullins, 1989) but increased in Belgium (Bockstaele et al., 1979). Lazim (1985) found seeds produced by transplanted plants were consistently heavier than those of direct-seeded corn.

The objective of this research was to determine the potential usefulness of seed hydration treatments and transplant management on sweet corn plant growth and development, earliness, and yield. Two genotypes, su and sh2 , both commercially important, were used because their respective stand establishment problems differ and are well known.

Materials and Methods

Stage of development. Thiram-treated seeds of sweet corn 'Yankee Belle' (Asgrow Seed Co., Nampa, Idaho), a *shrunken-*2 *(sh2) type,* and 'Banner' (Rogers Bros. Seed Co., Nampa, Idaho), a *normal sugary (su)* type, were subjected to six preplant treatments: 1) Control (dry) seed; 2) seed moistened for 12 hr (=30% moisture), 3) 24 hr (=38% moisture) in vermiculite (Bennett and Waters, 1987a); or 4) transplanted 4 days after seeding (DAS), 5) 7 DAS, or 6) 14 DAS into 4 x 7.5-cm cylindrical paper pots (Lannen, Camrillo, Calif.). Treatments 1 through 3 were planted 5 cm deep with a cone planter at twice the desired population, then thinned after emergence to 25-cm in-row spacings; treatments 4 through 6 were transplanted 25 cm apart with a Lannen transplater. All rows were 0.75 m apart. All treatments were planted or transplanted at the same time at each location and planting date.

The experiment was conducted at two Univ. of Minnesota locations: the Southern Experiment Station at Waseca on a Webster clay loam soil (fine-silty over sandy, mixed, mesic, Typic Haplaquoll) and at Becker on a Hubbard loamy sand soil (sandy, mixed Udorthentic Haploborall). One planting (26 Apr. 1985) was made at Becker with two-row plots, 0.76 x 20.6 m, and 1.5 m between plots and four replications in a randomized complete-block design. Two plantings (29 Apr. and 24 May 1985) were made at Waseca with three-row plots; otherwise, the study was the same as at Becker. Experiments in both locations were fertilized according to soil test results and commercial recommendations. Weeds and pests were controlled as required, using commercial recommendations.

Data collected were dates of emergence (Waseca only), 80% silk, and harvest; stand count; ear height, weight, length, number, and tip unfilled length; and plant height, weight, and stalk diameter at ear height. Harvest maturity was determined visually.

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Size vs. age. Thiram-treated seed of 'Yankee Belle' were planted 2.5 cm deep into a medium of 1 sand : 1 peat : 1 vermiculite (by volume) in cylindrical paper pots 4.5 cm deep x 2.5, 3.75, or 5 cm in diameter and grown in a greenhouse for 1.5, 2.5, or 3.5 weeks before transplanting into the field. Seedling heights for all container sizes were = 0 to 1 cm, 7 to 10 cm, and 12 to 16 cm, at 1.5, 2.5, and 3.5 weeks, respectively. The seedlings were transplanted into fields with a Lannen transplanter at the Waseca Station on 7 May 1985 and at Becker on 10 May 1985. Field plots at both locations consisted of single 7.6-m rows on 0.76-m centers with plants 25 cm apart. A split-plot experimental design with four replications was used, with age of the seedlings at transplanting as main plots and paper pot size as subplots. Plot management and data collected were the same as in the preceding experiment.

Holding of moistened seed. Thiram-treated seeds of 'Yankee Belle' and 'Banner' were moistened in vermiculite (as described under "Stage of Development") for 24 hr, then held at 10C for O, 1, or 3 days before planting in the field. Seed moisture levels at planting averaged 39%, 44%, and 48% after 0, 1, and 3 days holding, respectively. The moistened treatments were staggered for planting all treatments on the same day. The experiment was conducted at two locations: Waseca (see Stage of Development) planted 1 June 1985; and at St. Paul, Minn., planted 14 June 1985 on a Waukegan slit loam soil (fine-silty, mixed, mesic, Typic Hapludoll).

The experimental design at St. Paul was a split plot, with holding time as the main plot and the two cultivars as subplot factors. At Waseca, a randomized complete block was used. Both locations had four replications. A cone seeder was used to plant 60 seed per single-row plot (7.6 x 0.76 m) at a depth of 5 cm. After emergence, stands were thinned to 30 plants per row. At Waseca, in addition to variation in holding time, irrigation delays of 1, 2, or 4 days after planting were tested on seed moistened for 24 hr. Plot management and data collection were the same as in Expt. 1.

Results and Discussion

Stage of development. The treatments in this experiment represent a progression of developmental stages at planting, from nongerminated dry seed to seedlings of a relatively advanced stage of growth. Due to the great differences in the plant responses between 'Yankee Belle' and 'Banner', the data were analyzed separately. Generally, the response of 'Yankee Belle'

Table 1. Effects of seed moistening or transplanting on 'Banner' (*Su*) and 'Yankee Belle' (*sh2*) sweet corn growth and yield, as influenced by early or late planting dates, Waseca, Minn.[z]

Planting date	Treatment[y]	Interval to (days) Emergence	Silking	Harvest	Plant ht (cm)	Ear ht (cm)	Plant wt (g)	Ear length (cm)	Tip unfill (cm)	Plants (no./plot)	Ears (no./plot)	Yield (Mg·ha⁻¹)
						Banner						
Early	Seed											
	Dry	11.3 a	79 a	100 a	220 a	79 a	700 b	20.4 a	1.8 ab	32 a	30.3 a	18.6 a
	12 hr	10.0 a	78 a	99 a	214 ab	68 b	696 b	20.9 a	2.0 ab	31 a	26.5 a	16.1 a
	24 hr	10.0 a	78 a	99 a	223 a	75 a	677 b	20.5 a	2.7 b	31 a	29.3 a	17.3 a
	Seedlings											
	4 DAS	9.7 a	79 a	99 a	212 ab	61 b	921 c	21.1 a	1.3 a	25 c	27.3 a	18.0 a
	7 DAS	---	76 b	97 b	198 b	69 a	721 b	21.1 a	1.5 a	29 b	26.5 a	16.8 a
	14 DAS	---	74 b	95 b	200 b	61 b	520 a	21.2 a	1.4 a	31 ab	30.3 a	18.8 a
Late	Seed											
	Dry	7.3 a	72 a	93 a	227 a	83 a	538 a	19.2 a	1.2 a	34 a	37.0 a	19.0 a
	12 hr	6.5 a	71 a	93 a	223 a	77 ab	530 a	19.4 a	0.5 a	33 a	30.5 b	16.4 a
	24 hr	5.5 b	71 a	92 a	222 a	78 ab	531 a	18.8 a	0.6 a	31 a	34.3 ab	18.4 a
	Seedlings											
	4 DAS	4.0 c	70 b	91 a	227 a	74 ab	659 a	20.5 b	0.5 a	26 b	28.8 b	18.0 a
	7 DAS	---	67 c	88 b	217 ab	74 ab	609 a	19.8 ab	1.0 a	28 ab	30.3 b	16.8 a
	14 DAS	---	64 d	86 b	204 b	68 b	513 a	20.7 b	1.1 a	29 a	33.8 ab	18.8 a
						Yankee Belle						
Early	Seed											
	Dry	11.3 a	69 a	90 a	183 b	46 bc	778 a	21.2 ab	1.7 a	22 a	21.8 ab	14.2 a
	12 hr	11.3 a	69 a	90 a	186 a	50 c	713 a	21.1 ab	2.3 a	23 a	26.0 a	16.0 a
	24 hr	11.0 a	68 a	89 a	180 b	43 bc	779 a	21.0 ab	1.9 a	24 a	26.0 a	15.8 a
	Seedlings											
	4 DAS	13.5 b	70 a	92 a	174 bc	46 bc	989 b	22.0 a	1.8 a	12 b	15.3 b	9.7 b
	7 DAS	---	68 a	89 a	177 b	39 b	813 a	21.0 ab	2.5 a	23 a	25.8 a	16.4 a
	14 DAS	---	64 b	86 b	166 c	27 a	756 a	20.2 b	2.0 a	27 a	27.8 a	16.4 a
Late	Seed											
	Dry	8.3 a	60 a	81 a	182 a	55 b	620 ab	21.5 a	2.7 ab	28 a	25.5 a	13.5 a
	12 hr	7.3 a	61 a	82 a	181 a	53 b	651 ab	20.7 a	3.5 ab	30 a	24.5 a	12.1 a
	24 hr	7.3 a	60 a	81 ab	182 a	54 b	548 a	21.1 a	4.1 b	26 ab	26.5 a	13.9 a
	Seedlings											
	4 DAS	4.8 b	60 a	81 ab	179 a	52 b	727 bc	21.7 a	2.3 a	17 c	22.3 a	12.7 a
	7 DAS	---	59 b	80 b	197 a	47 ab	870 c	21.6 a	3.2 ab	22 b	20.5 a	12.1 a
	14 DAS	---	55 c	76 c	172 a	43 a	744 bc	21.9 a	2.9 ab	27 ab	25.5 a	14.9 a

[z]Separation of means within planting date and cultivar by Fisher's protected LSD, $P = 0.05$.
[y]Seed: planted dry or after 12 or 24 hr of imbibition; seedlings: transplanted 4, 7, or 14 days after seeding (DAS).

Table 2. Effects of seed moistening or transplanting on 'Banner' *(su)* and 'Yankee Belle' *(sh2)* sweet corn growth and yield, Becker, Minn.[z]

Cultivar	Treatment[y]	Days to 80% silking	Days to harvest	Plant ht (cm)	Plant wt (g)	Stalk diam (cm)	Ear length (cm)	Tip unfill/plot	Ear diam (cm)	Ear (no./plot)
Banner	Dry	87 b	109 a	95 a	689 abc	2.4 bc	20.2 bcd	1.6 d	4.3 ab	51.5 ab
	12 hr	88 b	109 a	91 bc	617 cd	2.5 ab	19.6 d	2.1 abc	4.4 a	52.0 a
	24 hr	87 b	107 ab	92 b	758 a	2.5 ab	20.1 bcd	1.7 cd	4.3 abc	48.5 ab
	4 DAS	82 a	102 bc	88 cd	662 bc	2.6 ab	20.7 ab	1.8 bcd	4.2 bcd	43.3 b
	7 DAS	82 a	104 abc	86 de	601 cde	2.7 a	19.8 cd	1.0 e	4.3 ab	50.8 ab
	14 DAS	81 a	100 cd	83 f	553 def	2.3 c	20.2 bcd	1.1 e	4.3 abc	50.8 ab
Yankee Belle	Dry	77 bc	95 cd	82 b	503 e	2.2 b	20.3 a	2.5 b	3.8 ef	47.0 a
	12 hr	77 c	99 abcd	79 c	519 de	2.2 b	20.6 a	2.3 bc	4.0 de	50.8 a
	24 hr	78 c	100 abc	83 b	551 cde	2.4 a	20.3 a	2.1 bcd	4.1 cd	50.8 a
	4 DAS	82 d	101 a	83 ab	723 ab	2.4 a	21.0 a	1.8 de	4.3 abc	34.0 b
	7 DAS	74 ab	95 cd	72 d	365 f	1.9 c	20.4 a	2.3 bc	3.7 f	45.5 a
	14 DAS	73 a	94 d	71 d	356 f	1.9 c	20.7 a	3.1 a	3.7 f	44.5 a

[z]Separation within' columns and within cultivars by Fisher's protected LSD, $P = 0.05$.
[y]3eed: planted dry or after 12 or 24 hr of imbibition; seedlings: transplanted 4, 7, or 14 days after seeding (DAS).

Table 3. Influence of age at transplanting and paper pot size on number of days from seeding to harvest for 'Yankee Belle' *(sh2)* sweet corn, Waseca, Minn.

Analysis of variance	df	MS	F	*P* value
Age	2	75.9	78.0	<0.001
Error	6	0.97		
Paper pot size	2	17.7	13.8	<0.001
Age x size	4	5.4	4.2	0.014
Error	18 .	1.29		

Age of seedlings (weeks)	Paper pot diam (cm) 2.5	3.75	5.0
	Days to harvest[z]		
1[y]	83 b	82 b	80 a
2	80 b	76 a	76 a
3	77 a	76 a	77 a

[z]Mean separation within rows and columns by Fisher's protected LSD at $P = 0.05$.
[y]Weeks after seeding at transplanting.

Table 4. Influence of age at transplanting on plant growth and development and yield of 'Yankee Belle' *(sh2)* sweet corn, at Waseca, Minn.

Criterion	Age of seedlings (weeks) 1	2	3
No. plants/plot	19.7 b[z]	28.4 a	24.8 a
Plant height (cm)	155 a	141 b	133 c
Plant weight (g)	698 a	433 b	377 b
Stalk diameter (cm)	2.0 a	1.8 ab	1.7 b
Ear height (cm)	33.3 a	22.3 b	16.7 c
Ear diameter (cm)	4.7 a	4.4 b	4.5 b
Ear length (cm)	21.1 a	20.3 ab	19.5 b
Yield ($Mg \cdot ha^{-1}$)	16.0 a	16.1 a	12.0 b

[z]Mean separation within rows and columns by Fisher's protected LSD, $P = 0.05$.

to the treatments was more dramatic than that of 'Banner', as was expected. Data are shown (Tables 1, Waseca, and 2, Becker) only for those characteristics for which some significant response was obtained. The use of moistened seed (12 and 24 hr) had little or no effect beyond emergence and early seedling development on any of the variables measured at either location or for either cultivar, a finding in general agreement with previous results (Bennett and Waters, 1987a, 1987b).

The time required to achieve specific postplanting stages of plant development (emergence, silking, and harvest) was reduced at the Waseca site (Table 1) by progressive seedling development at planting, with a few exceptions. The use of nonemerged transplants (4 DAS) delayed emergence for 'Yankee Belle', and at Becker, delayed maturity (Table 2). Maturity of 'Banner' at Becker was advanced by 6 to 8 days with the use of transplants.

There was little consistent effect of any of the treatments on ear development or ear characteristics. The most important commercial characteristic, unhusked ear yield, was generally not affected by the treatments used at Waseca (Table 1), and there was no effect at Becker. At Waseca, the use of nonemerged seedlings (4 DAS) reduced yield of 'Yankee Bell'. Only the 12-hr moisturization treatment reduced yield of 'Banner', though not significantly.

Transplanting tended to reduce the number of plants surviving until harvest, plant height, and ear height at Waseca (Table 1). The effect of transplanting on plant height at Becker was not as consistent as at Waseca, but showed the same general trend (Table 2). Although the treatment effects on average plant weight were not consistent at either location, the strongest tendency was for the nonemerged (4 DAS) seedlings to give higher plant weights. The low plant populations of the 4 DAS treatment (Table 1) may account for some of the increase in plant weight.

Overall, the use of transplants in this experiment gave little response beyond decreasing percent survival and plant height. Even though the number of days to maturity was reduced in most cases for the 7 and 14 DAS treatments, the number of days of advantage was much less than the age of the seedling when transplanted; however, under adverse field conditions, transplanting may still be advantageous. This finding is consistent with other reports (Carrunza and Vicuna, 1978; Flood-Page, 1976; Lendent et al., 1980, 1981; Miller, 1972; Pendleton and Egli, 1969), but few explanations are presented for this negative impact. In our opinion, a large part of the transplanting shock alluded to by others involves the nature of corn root system development. Kiesselbach (1980) has shown that the initial seminal roots of field corn grow in a nearly horizontal direction when soils are cool or cold, but vertically in warm soils, and that the loss of initial seminal roots can reduce grain yield.

Data were not collected on root development of the containerized seedling treatments, but it was noted that roots had not developed sufficiently by 4 DAS to maintain the root–soil mass

Table 5. Influence of preplant holding (10C) duration of moistened 'Yankee Belle' *(sh2)* and 'Banner' *(su)* sweet corn seed.'

Criterion	Banner 0	Banner 1	Banner 3	Yankee Belle 0	Yankee Belle 1	Yankee Belle 3
	Duration (days)					
St. Paul						
Stand count[y]	47 a	45 a	50 a	46 a	45 a	43 b
Days to silking	65 c	65 c	65 c	56 b	54 a	55 ab
Days to harvest	89 c	89 c	89 c	81 b	83 b	76 a
Yield ($Mg\cdot ha^{-1}$)	15.0 a	15.0 a	14.7 a	8.5 c	9.3 c	11.5 d
Ear diameter (cm)	4.0 a	4.0 a	4.0 a	3.8 b	3.8 b	3.5 b
Ear length (cm)	19.7 a	19.8 a	19.7 a	20.0 a	19.9 a	21.3 b
Plant height (cm)	94 a	93 a	76 c	87 b	84 b	76 c
Plant weight (kg)	1.8 a	1.8 a	1.9 a	1.4 b	1.4 b	1.7 a
Stalk diameter (cm)	2.5 a	2.4 a	2.5 a	2.2 b	2.2 b	2.1 b
Tip unfill (cm)	0.7 a	0.8 a	0.6 a	1.9 b	2.3 b	0.8 a
Waseca						
Stand count[y]	29 b	28 b	30 b	29 b	25 a	25 a
Plant weight (kg)	2.4 d	2.1 c	2.0 c	1.3 ab	1.5 b	1.2 a

[z]Separation within rows by Fisher's protected LSD at $P = 0.05$.
[y]Mean number of emerged seedlings per 60 seeds planted.

intact during planting. Further, the primary and seminal roots that developed did not appear to "bind" to the media in the same way as root systems of other plants. The lack of root development may have been involved in the negative impact of the nonemerged seedling treatment (4 DAS) on various criteria. Observation of the corn roots in this and other studies shows that root hair development is less extensive than in dicotyledonous plants, which could account for the failure to bind to the media, resulting in breaking during handling. This breakage could contribute to the negative results generally found with sweet corn transplanting.

Size vs. age. Increasing the seedling age at the time of transplanting decreased the time to harvest by as much as 6 days at Waseca (Table 3). The 2- and 3-week treatments did not differ significantly, except within the smallest (2.5 cm) paper pots. Paper pot size had no effect "on days to harvest for the 3-week-old transplants; however, the largest size decreased the time to harvest for both 1- and 2-week-old transplants. The medium-sized container also reduced time to harvest for 2-week-old seedlings. The response to treatments was similar for the number of days to silking.

Plant growth and yield generally decreased with increased age at the time of planting (Table 4). Since plant survival was greater for the 2- and 3-week-old transplants, some of the decrease in plant size and yield may be due to the greater plant density of those treatments. However, the 3-week-old transplants, which had a lower population than those 2 weeks old, also showed lower ear height and yield.

No significant effects of transplant age or paper pot size were noted at Becker; however, the 2-week-old seedlings generally gave the best response (data not presented). The generally superior performance of younger plants and the smaller paper pot sizes may relate to the root development phenomena discussed above. There was probably greater damage to roots of older plants in handling, with a commensurate increase in transplant shock. The smaller the paper pot size, the better the root mass held together in handling, thereby protecting the roots from breakage.

Holding of moistened seed. While the values for the two cultivars were different, storage of moistened sweet corn seed at 10C for up to 3 days appears feasible for both cultivars. Holding moistened 'Banner' seed for 1 or 3 days before planting decreased plant height at St. Paul and plant weight at Waseca, but had no significant effects on yield or earliness (Table 5). Moistened 'Yankee Belle' seed held for 3 days showed a slight decrease in stand establishment, and yields were greater at St. Paul, compared with the O- or l-day holding treatments. Some radicles had emerged from seeds held for 3 days.

Table 6. Influence of delaying postplanting irrigation of moistened 'Yankee Belle' *(sh2)* and 'Banner' *(su)* sweet corn seed on growth criteria (Waseca).

Duration to growth criterion (days)	Banner 1	Banner 2	Banner 4	Yankee Belle 1	Yankee Belle 2	Yankee Belle 4
	Delay (days)					
Emergence	7.5 a[z]	8.0 ab	8.0 ab	8.0 ab	8.0 ab	8.5 b
Silking	69 c	69 c	70 c	58 a	58 a	61 b
Harvest	81 a	82 a	84 b	90 c	90 c	91 d

'Separation within rows by Fisher's protected **LSD** at $P = 0.05$.

Delaying irrigation until 4 days after planting tended to increase the days to emergence, silking, and harvest for both cultivars, compared to plots that were irrigated 1 to 2 days after planting (Table 6). These data suggest that delaying irrigation following the seeding of moistened sweet corn seed, regardless of the cultivar, may have minimal impact if the delay is only 1 or 2 days. Preplant irrigation, an often recommended practice, could further reduce any negative impact of irrigation delay on plant growth and development.

The results of these experiments indicate that preplant moisturization of seed is not detrimental and that sweet corn is not particularly sensitive to the often-cited problems of having to hold seed in a moistened condition before seeding or to a delay in irrigation after planting. The use of transplants, however, requires further research before it becomes an economically viable practice. Further research on transplant production and planting should probably focus on the characteristics of root development, with particular emphasis on the media used, the temperature of the media following seeding, and on modified handling practices to protect roots from damage.

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