Seed Size/Shape and Tillage System Effect on Corn Growth and Grain Yield

L. M. Graven and P. R. Carter*

This research was conducted to evaluate the effects of corn (*Zea mays* L.) seed size/shape on field performance of commercially available corn hybrids under conventional tillage (CT) and no-tillage (NT). Field studies were conducted in 1987 and 1988 under the two tillage systems with small-round, small-flat, large-round, and large-flat seed of hybrids LH74xLH51 and A632xLH39, on Plano silt loam (fine, mixed, mesic Typic Argiudoll) soil at Arlington and Janesville, WI. At Arlington, there were also early (mid- to late-April) and late (mid- to late-May) planting dates. Under such stressful conditions as early planting, NT, and soil crusting during emergence, small-round seed often was 5 to 15% lower in emergence than small-flat and large-round seed. Emergence rate, vegetative dry weight, silk date, grain yield (at similar stands accomplished by overplanting and thinning), and other growth parameters measured were not influenced consistently by seed size/shape. No-tillage and early planting resulted in cold soil at planting, which delayed emergence, early growth, and silking and often reduced grain yield compared with CT, but tillage system by seed size/shape interactions were not important for these factors. These results indicate that corn producers should focus on genetic potential, seed quality, and seed price rather than specific seed sizes/shapes when selecting hybrids, except when planting under stressful conditions. With very early planting or NT, it may be advisable to avoid small-round seed, or to increase seeding rate by 10 to 15% with this seed size/shape in order to obtain the desired stand.

CORN SEED size and shape vary due to genetics, environment, and location of kernels on the ear. Seed of three- or four-way cross hybrids is generally larger than seed of single-cross hybrids. Seed size is also dependent on environmental conditions during plant development and grain fill. Stresses such as high temperature, low soil moisture, or low fertility can decrease seed size (4). Lastly, placement of seed on the ear affects both seed size and shape. Due to the sequential development of the corn ear from the base to the tip and the resulting range in photosynthate availability, seed from a single ear can fall into many size/shape categories. Large-round classes usually come from the base of the ear, flats from the center, and small-round seed from the tip.

With the introduction of plateless planters, corn producers are better able to plant seed of any size/shape combination without obtaining plates of the proper size. However, either medium-flat or large-flat seed remains the choice of many farmers, despite greater cost than the other seed size/shape combinations or mixtures. This is due to the concern that small

---

Dep. of Agronomy, Univ. of Wisconsin, Madison, WI 53706. Received October 1989. *Corresponding author.

Published in J. Prod. Agric 3:445–452 (1990).

and/or round size/shape combinations may not have the performance potential of other seed classes. Smaller sizes of early three-way and four-way crosses and of single crosses introduced in the early 1960s were discarded, but it became commercially feasible for seed companies to sell all sizes. This has increased the proportion of small seed sold within the past 10 to 15 yr. Also, severe drought in many seed-producing areas in 1988 resulted in greater quantities of small seed than usual.

Several studies have considered the relative performance of size/shape combinations, and have found few differences in emergence, growth, or grain yield. Kiesselbach (13) found that kernels taken from the base, tip, and middle of open-pollinated ears did not differ in plant development or grain yield. Hunter and Kannenberg (11) evaluated large and small seed of single cross hybrids with equal warm germination tests at three dates of planting and three planting depths. The only difference between large and small seed was in early season plant height, with the plants from the small seed being slightly shorter. In a controlled-environment study, they found no effect of seed size on rate or extent of emergence for three temperature regimes and three planting depths. Hicks et al. (9) compared large-round, large-flat, small-round, small-flat, and mixed seed classes of single-cross hybrids at two planting dates and two locations. The effects of seed class on plant growth and development were minor. For grain yield, the seed class by planting date interaction was nonsignificant for three of four location-years of the study. In just one of 12 comparisons was there a seed class effect, with higher yields from graded vs. mixed seed,large vs. small seed, and round vs. flat seed. Munchena and Grogan (16) found that small seed had higher germination than large seed when a popcorn hybrid and two dent inbred lines were grown in simulated water-stress conditions. They suggested that the smaller seed may have required less water for germination due to a smaller volume.

Since these studies were conducted, new hybrids have been developed and corn acreage planted using conservation tillage has increased. Colder, wetter soil under conservation tillage, particularly no-tillage systems, creates a stressful environment that frequently reduces emergence, delays growth, and lowers grain yield in Northern areas (1, 6, 12). The objective of this study was to evaluate the effect of seed size/shape combinations on the emergence, seasonal development, and grain yield of corn under conventional and no-tillage systems.

MATERIALS AND METHODS

Seed lots of two commonly-grown hybrids (LH74xLH51, 110-d relative maturity [RM]; and A632xLH39, 100-d RM) that had been conditioned and treated with captan (cis-N-[{trichloro methyl}thio]-4 cyclohexene-1,2-dicarboximide) were obtained from several seed companies. Size and shape classifications of all lots were verified according to (i) the procedures used by the Wisconsin Crop Improvement Association (WCIA) (20), and (ii) 100-kernel weight measurements. The WCIA procedure separates seed on the basis of size and shape using screens with varying slot widths and shapes (21).

Cold germination tests were conducted on the lots according to the procedures described in the Seed Vigor Testing Handbook (2), using WCIA facilities and modifications (10, 20). In the cold germination test, four replicates of 50-kernel samples of the seed-lots were placed on two paper towels that had been soaked in cold water and covered with saturated, high organic matter peat soil that was collected from a corn field. A third wet towel was placed over the seeds and soil and the towels were rolled and placed on end in an aluminum box. The boxes were placed in a germination chamber at 50°F for 7 d and then moved to a chamber at 78°F for 4 d. The numbers of nonviable, abnormal- and normal-germinated seedlings were then counted, using Association of Official Seed Analysts (AOSA) rules for seedling evaluation (3). Warm germination tests were conducted according to AOSA rules (3), except that only four replicates of 50-kernel samples of the seed lots were evaluated. For both cold and warm germination tests, there was no addition of light and daily temperatures were constant. Based on the cold test results, appropriate lots of each hybrid were selected for field research. These included four lots of each hybrid with similar cold germination characteristics (approximately 90%) and (i) small-round, (ii) small-flat, (iii) large-round, and (iv) large-flat size/shape combinations (Table 1). Seed not planted in 1987 was stored at 50°F and 50% relative humidity and was subjected to cold and warm germination tests twice before planting the 1988 studies.

Mechanical damage to the pericarp was evaluated using fast green dye staining (14) on 100-kernel samples of each lot (Table 1). Damaged kernels were those which (i) had staining over the plumule indicating pericarp breaks over the embryo or (ii) those with staining that extended more than 75% of the distance from the pedicel area to the embryo apex on both sides of the embryo, indicating a separation of the pericarp from the seed. These criteria were selected on the basis of tests by Tatum and Zuber (19) and Koehler (14) which showed that damage to the embryo or to the pericarp surrounding the embryo lowered cold germination scores more than any other type of pericarp damage.

Studies were conducted on Plano silt loam soils at Arlington and Janesville, WI, in 1987 and 1988 on sites that had been in corn production previously. The four seed size/shape combinations for each hybrid were evaluated under conventional tillage (CT) and no-tillage (NT) systems at both locations, and with early and late planting dates only at Arlington. Planting dates at Arlington were 27 Apr. 1987 and 18 Apr. 1988 (early) and 26 May 1987 and 12 May 1988 (late). At Janesville, the planting dates were 28 Apr. 1987 and 2 May 1988.

Table 1. Size/shape, weight, cold and warm germination percentage, and pericarp damage of seed used in field studies.

Hybrid	Size/shape	Round-hole screen size		80 000 Kernel weight	Germination†		Pericarp‡ damage
		Through	Over		Cold	Warm	
		in.		lb	%		
LH74×LH51	Small round§	18/64	16/64	39	91(3.6)	92(4.6)	36
	Small flat	17/64	15/64	31	92(3.1)	91(4.0)	25
	Large round	21/64	18/64	49	92(1.9)	93(3.1)	28
	Large flat	21/64	18/64	43	92(3.4)	96(2.1)	34
A632×LH39	Small round	18/64	15/64	35	91(2.6)	92(4.4)	24
	Small flat	18/64	15/64	31	93(3.9)	97(2.6)	22
	Large round	23/64	20/64	55	91(3.3)	94(3.1)	18
	Large flat	23/64	21/64	51	92(3.1)	93(2.8)	14
LSD (0.05)				1	NS	2	4
CV (%)				1.3	3.6	3.1	11.6

† Cold and warm germination values are averages of three tests conducted February–March 1987, September 1987, and March 1988. Standard deviations are indicated in parentheses.

‡ Pericarp damage based on fast green dye test (14) and includes seed with pericarp damage over the plumule within the embryo or seed with damage to the region surrounding the embryo.

§ Round seeds were those passing over 12/64-in. (small) or 13/64-in. (large) slotted-hole screens.

At both locations, CT consisted of fall moldboard plowing to a depth of 7 in., and disking once or twice prior to planting. No-tillage was planting directly into unincorporated corn residue with only a 1 in. band disturbed for seed placement. Corn was planted at the rate of 44 500 kernels/acre using cone-seeders on a four-row, no-till corn planter equipped with rippled coulters, heavy-duty down-pressure springs, double-disk openers, and cast iron press wheels (Kinze Manufacturing, Williamsburg, IA).

Soil tests indicated a pH of 6.1, 84 lb P/acre, and 374 lb K/acre at Arlington. Plots received yearly applications of 9-17-30 lb/acre of N-P-K as row-applied starter fertilizer at planting, and 200 lb N/acre supplied as ammonium nitrate broadcast over the entire area prior to planting. Terbufos (S-[{1,1-dimethylethylthio}methyl]-0,0-diethyl phosphorodithioate) was applied at planting at a rate of 7 lb/acre for corn rootworm (*Diabrotica* spp.) control. Pre-emergence applications of atrazine (6-chloro-*N*-ethyl-*N*-[methyl ethyl]-1, 3, 5-triazine-2, 4-diamine) and metolachlor (2-chloro-*N*-[2-ethyl-6-methylphenyl]-*N*-[2-methoxy-1-methylethyl] acetamide) both at 3 lb/acre were used in 1987 for annual weed control and metolachlor and cyanazine (2-[{4-chloro-6-(ethylamino)-1, 3, 5-triazin-2-yl} amino]-2-methylpropionitrile) both at 3 lb/acre were applied in 1988. Fenvalerate (cyano [3-phenoxyphenyl] methyl 4-chloro-*α*-[1-methyl ethyl] benzeneacetate) was applied at a rate of 0.05 lb/acre at silking in 1988 to prevent silk feeding by corn rootworm beetles.

Soil tests at Janesville indicated a pH of 6.5, 135 lb P/acre, and 405 lb K/acre. All plots received yearly applications of 225 lb N/acre supplied as urea-ammonium nitrate sidedressed post emergence. Applications of starter fertilizer, herbicides,and insecticides were similar to those at Arlington, except that the chemical for control of corn rootworm beetles was not applied. Also, plots were cultivated in 1988 due to lack of adequate chemical weed control.

The experimental design was a randomized complete block in a split-plot arrangement with three replicates at Janesville and four at Arlington. At Arlington, main plots were a factorial combination of the two tillage systems and two dates of planting. The four seed size/shape combinations and the two hybrids were assigned to subplots in a factorial arrangement. Main plots at Janesville were the two tillage systems, and subplots were the same as at Arlington. Subplots at both locations were four, 30-in. wide by 30-ft long rows. Planting dates and subplots (hybrids and seed size/shapes) were randomized in 1987 and rerandomized in 1988. Tillage treatments were initiated in 1984 as part of a long-term study at both locations and remained in the same position for the duration of the study.

Midday temperatures in the row (2-in. depth) were recorded daily for each tillage system at Arlington from planting to 30 d after planting and at planting for Janesville. Residue cover percentage was estimated before seedling emergence using the line intersect method (7). Emerged seedlings were recorded daily at Arlington until plant number stabilized. Days-to-emergence was computed as days after planting until 75% of final emergence. At both locations, percent emergence was determined as the number of seedlings emerged as a percentage of kernels planted.

When corn under CT reached the V6 stage (17), plots were hand thinned to 25 000 plants/acre. At thinning, 10 plants were randomly selected from each subplot, harvested at ground level, and dried in a forced-air oven to determine vegetative dry weight. Days from planting to silk were recorded at Arlington only. Silking date was defined as the date when 50% of the plants had emerged silks.

Final stand (plants/acre), and mature plant height (inches to the flag leaf collar) were determined at harvest at both locations. Plots were harvested with a two-row plot combine and grain moisture percentage and grain yield were measured for the two interior rows of each sub-plot. Grain yields were converted to bu/acre at 15.5% moisture. Harvest dates were 12 Oct. 1987 and 3 Oct. 1988 at Arlington and 6 Oct. in both 1987 and 1988 at Janesville.

Analyses of variance were computed for data from each location and year. In the analysis, all effects except replicates were considered fixed.

RESULTS AND DISCUSSION

For cold germination tests, standard deviations within seed size/shape categories were low, and there were no differences between hybrids or among seed sizes/shapes when averaged over the three tests (Table 1). Cold germination tests did not change with time (data not shown), indicating that seed vigor did not decline during seed storage. For the warm germination tests, there were slight differences between seed size/shape combinations of the two hybrids and among seed sizes/shapes within hybrids when averaged over the three tests (Table 1). There were also small differences between and among the tests over time. However, these differences were inconsistent and trends toward a decline with time could not be detected. Gill and Delouche (8) also found that warm and cold germination tests of seed stored at 45°F and 50% RH did not decline over an 18-mo period.

Table 2. Precipitation and mean air temperature for the 1987 and 1988 growing seasons at Arlington and Janesville.

Month	Arlington 1987	Arlington 1988	Janesville 1987	Janesville 1988
		Temperature		
		°F		
May	60.7 (+2.9)†	62.6 (+4.8)	63.9 (+3.6)	61.6 (+1.3)
June	70.7 (+4.0)	71.6 (+4.9)	66.3 (−3.4)	70.2 (+0.5)
July	74.5 (+3.5)	75.0 (+4.0)	73.2 (−0.6)	75.4 (+1.6)
August	68.5 (−0.4)	74.7 (+5.8)	68.8 (−3.1)	74.4 (+2.5)
September	61.7 (+0.8)	64.4 (+3.5)	64.7 (+0.8)	63.6 (−0.3)
Season Mean	67.2 (+2.2)	69.7 (+4.6)	67.4 (−0.5)	69.0 (+1.1)
		Precipitation		
		in.		
May	4.7 (+1.6)	1.0 (−2.2)	3.4 (+0.2)	1.0 (−2.2)
June	0.6 (−3.5)	1.5 (−2.6)	1.6 (−2.4)	1.2 (−2.8)
July	4.0 (+0.5)	1.6 (−2.0)	3.4 (−0.7)	1.3 (−2.8)
August	4.9 (+0.9)	2.9 (−1.2)	5.7 (+1.9)	4.2 (+0.4)
September	4.9 (+1.3)	3.9 (+0.3)	1.8 (−1.6)	3.4 (0)
Season Total	19.1 (+0.1)	10.9 (−7.7)	15.9 (−2.6)	11.1 (−7.4)

† Number in parentheses indicates the deviation from the long-term average.

The fast green dye test revealed differences in pericarp damage among the seed lots (Table 1). Damage was greatest for seed of hybrid LH74xLH51, in particular for small-round and large-flat sizes/shapes. For the small-round seed of LH74xLH51, pericarp damage generally occurred around the embryo perimeter and over the plumule, while damage for the large-flat seed of this hybrid occurred at the pedicel and lower third of the embryo. Mechanically harvested and processed seed corn often contains 20 to 30% pericarp-damaged seed with levels above 30% causing some concern to seedsmen (M. Anfinrud, 1988, Interstate Seed Co., personal communication). Since pericarp damage occurs primarily during seed conditioning (21) and since the seed lots used in this study were supplied by several companies, differences in pericarp damage probably were due to differences in seed handling and processing methods between the companies and not to specific hybrid or seed size/shape effects.

The lack of differences in cold germination tests, in

Table 3. Main effects and significance of two-way interactions for tillage system (T), planting date (D), and hybrid (H) for corn growth and yield for two growing seasons at Arlington. Main effect values are averages of four seed sizes/shapes and the two other main effects.

	Tillage System (T)		Planting Date† (D)		Hybrid (H)					
	Conv.	No-till	Early	Late	LH74 × LH51	A632 × LH39	T × D	T × H	D × H	CV
							P > F‡			%
1987										
Residue cover (%)	4 *	82	43	42			0.03			5.2
Soil temperature (°F)§	71.1*	67.6	59.6*	79.1			NS			1.9
Emergence (%)	80.2*	83.9	87.8*	76.4	82.6	81.5	0.02	NS	NS	7.6
Days to 75% emergence	10.6*	14.5	17.1*	8.0	12.1	13.0	<0.01	NS	NS	6.6
Vegetative dry wt. (oz/10 plants)	3.0*	2.0	2.1*	2.9	2.5	2.5	NS	NS	NS	22.8
Days to 50% silking	71.6*	75.2	80.9*	65.9	74.9*	71.9	NS	<0.01	<0.01	1.5
Mature plant ht (in.)	74.0*	77.9	74.4	77.1	77.9*	73.6	NS	NS	0.04	6.5
Final stand (plants/acre × 1 000)	23.7	23.9	24.4*	23.2	24.0*	23.6	NS	NS	<0.01	3.8
Grain moisture (%)	25.1*	28.3	22.4*	31.0	29.9*	23.6	<0.01	NS	<0.01	5.4
Grain yield (bu/acre)	131	126	133 *	123	143 *	114	NS	NS	NS	8.3
1988										
Residue cover (%)	3 *	83	44	43			NS			11.8
Soil temperature (°F)	63.9*	59.5	50.2*	73.1			<0.01			2.4
Emergence (%)	83.0*	70.9	70.2*	83.6	76.2	77.7	NS	NS	NS	9.8
Days to 75% emergence	15.5*	21.4	26.8*	10.1	17.7	19.2	<0.01	NS	<0.01	7.1
Vegetative dry wt. (oz/10 plants)	2.1*	0.6	1.2*	1.5	1.4	1.3	0.03	0.04	0.02	22.8
Days to 50% silking	82.4*	95.5	98.6*	79.3	90.5*	87.4	NS	<0.01	NS	2.2
Mature plant ht (in.)	79.9*	77.1	77.1*	80.3	79.1	78.3	NS	0.02	NS	5.3
Final stand (plants/acre × 1 000)	25.1	24.8	24.4*	25.5	25.2*	24.7	0.03	NS	NS	5.1
Grain moisture (%)	25.4*	36.0	32.3*	29.1	32.9*	28.5	<0.01	<0.01	NS	8.5
Grain yield (bu/acre)	83 *	69	67 *	84	83 *	68	NS	0.03	NS	16.6

* Differences between tillage systems, planting dates, or hybrids are significant at $P < 0.05$.

† Early = 27 April 1987 and 18 April 1988, Late = 26 May 1987 and 13 May 1988.

‡ P values for the two-way interactions of tillage system (T) × planting date (D), tillage system (T) × hybrid (H), or planting date (D) × hybrid (H).

§ Midday in-row soil temperature at planting depth (2 in.) averaged over 7 d following planting.

spite of differences in pericarp damage between seed lots (Table 1), suggests either that damage was not severe enough to limit laboratory cold germination, or that cold test severity was insufficient to reveal effects of pericarp damage on germination. Correlations between pericarp damage and low-temperature germination tests have been high (14, 15). In contrast to our tests, these studies used seed that had not been treated with fungicides (14, 15) or the seed was held at 50°F for 10 d in the cold germination test (14) compared with 7 d in our tests.

Growing season air temperature and precipitation in 1987 at Arlington and Janesville were generally similar to long-term averages, except for a low-rainfall period in June (Table 2). In contrast, 1988 temperatures were above normal and precipitation was below average, particularly at Arlington (Table 2). This resulted in severe drought, which decreased grain yields at both locations, but the level of reduction was greater at Arlington (Tables 3–6).

Tillage, planting date, and hybrid main effects and interactions were generally similar to previous results obtained for corn-after-corn on silt loam soils in other Northern Corn Belt studies (Tables 3 and 4) (1, 6, 12, 18). Under NT, in-row residue cover and cool soil temperatures delayed growth and often lowered grain yields. Late planting at Arlington resulted in warmer soil and more rapid plant development than with early planting (Table 3). In 1987, late planting reduced grain yields, but in 1988 yields were increased with delayed planting (Table 3). Corn plants within both planting dates were subjected to long periods of severe moisture stress and high temperatures in 1988, but increased rainfall during August (Table 2) was evidently more beneficial to late-planted corn. The later-RM hybrid LH74xLH51 yielded more grain than A632xLH39 in all environments (Tables 3 and 4). A tillage system × hybrid interaction for grain yield occurred only in 1988 at Arlington (Table 3). Grain yields were 33% lower for the hybrid A632xLH39 under NT than with CT, but the yields were only 19% lower under NT than CT for LH74xCH51.

For the parameters we evaluated, seed size/shape response for main effects or interactions was greatest for percent emergence at Arlington in 1987 and 1988 (Table 5) and at Janesville in 1987 (Table 6). In 1987, tillage system × seed size/shape interactions for percent emergence occurred at both locations (Tables 5 and 6, Figs. 1A and 1B). At Arlington, percent emergence was similar for seed size/shape combinations

Table 4. Main effects and significance of two-way interactions for tillage system (T) and hybrid (H) for corn growth and yield for two growing seasons at Janesville. Main effect values include averages of four seed sizes/shapes and the other main effect.

	Tillage System (T)		Hybrid (H)			
	Conv.	No-till	LH74 × LH51	A632 × LH39	T × H	CV
					$P > F$†	%
1987						
Residue cover (%)	2 *	82				11.7
Soil temperature (°F)‡	73.4*	69.9				2.1
Emergence (%)	84.5	83.2	81.8*	85.9	NS	4.9
Veg. dry wt. (oz/10 plants)	2.3*	1.2	1.7	1.8	NS	16.5
Mature plant ht (in.)	74.0	72.4	74.8*	70.8	<0.01	2.6
Final stand (plants/acre × 1 000)	23.3	23.1	23.4	23.0	NS	3.3
Grain moisture (%)	21.6*	24.6	25.4*	20.8	NS	4.0
Grain yield (bu/acre)	140 *	110	135 *	115	NS	12.1
1988						
Residue cover (%)	3 *	68				21.6
Soil temperature (°F)	65.7*	58.9				7.3
Emergence (%)	85.8	84.1	83.7	86.1	NS	5.1
Veg. dry wt. (oz/10 plants)	1.9*	0.8	1.4	1.4	NS	17.9
Mature plant ht (in.)	72.4*	81.5	81.1*	72.8	<0.01	3.5
Final stand (plants/acre × 1 000)	24.5	25.0	25.3*	24.3	NS	2.8
Grain moisture (%)	23.5*	28.6	29.3*	22.8	<0.01	6.9
Grain yield (bu/acre)	117	110	133 *	94	NS	8.0

* Differences between tillage systems or hybrids is significant at $P < 0.05$.
† P value for tillage system (T) × hybrid (H) interaction.
‡ Midday, in-row soil temperature, 2 in. depth, at planting.

Table 5. Seed size/shape (S) main effects and significance of two-way interactions with hybrid (H), planting date (D), and tillage system (T) for corn growth and grain yield for two growing seasons at Arlington. Main effect values are averages of two tillage systems, two planting dates, and two hybrids.

	Seed size/shape (S)†							
	SR	SF	LR	LF	LSD (0.05)	S × H	S × D	S × T
						$P > F$‡		
1987								
Emergence (%)	78.5	83.9	83.8	82.0	3.2	NS	NS	0.04
Days to 75% emergence	12.7	12.5	12.3	12.7	NS	NS	NS	NS
Veg. dry wt. (oz/10 plants)	2.5	2.5	2.8	2.4	NS	<0.01	NS	NS
Days to 50% silking	73.4	73.6	72.8	73.8	0.7	NS	NS	NS
Mature plant ht (in.)	76.8	77.1	75.6	73.6	2.5	NS	NS	NS
Final stand (plants/acre × 1 000)	23.6	23.8	24.0	23.8	NS	NS	<0.01	<0.01
Grain moisture (%)	26.3	27.2	25.7	27.7	0.7	NS	NS	0.02
Grain yield (bu/acre)	128	128	127	130	NS	NS	NS	NS
1988								
Emergence (%)	74.4	82.7	77.1	73.6	3.8	<0.01	<0.01	NS
Days to 75% emergence	18.3	18.3	17.9	19.3	0.7	NS	NS	NS
Veg. dry wt. (oz/10 plants)	1.5	1.2	1.4	1.3	0.1	NS	NS	NS
Days to 50% silking	88.3	89.3	88.4	89.8	1.0	NS	NS	NS
Mature plant ht (in.)	78.3	78.7	77.9	79.5	NS	NS	NS	NS
Final stand (plants/acre × 1 000)	25.1	25.6	24.9	24.3	0.6	NS	NS	NS
Grain moisture (%)	30.5	30.1	30.1	32.1	1.3	NS	NS	NS
Grain yield (bu/acre)	75	78	75	74	NS	NS	NS	NS

† SR = small round, SF = small flat, LR = large round, LF = large flat.
‡ P values for seed size/shape (S) × hybrid (H), seed size/shape (S) × planting date (D), or seed size/shape (S) × tillage system (T) interactions.

Table 6. Seed size/shape (S) main effects and significance of two-way interactions with hybrid (H), and tillage system (T) for corn growth and grain yield for two growing seasons at Janesville. Main effect values are averages of two tillage systems and two hybrids.

	Seed size/shape (S)†						
	SR	SF	LR	LF	LSD (0.05)	S × H	S × T
						— $P > F$‡ —	
1987							
Emergence (%)	82.3	86.3	84.4	82.3	NS	NS	0.03
Veg. dry wt. (oz/10 plants)	1.9	1.6	1.8	1.7	NS	NS	NS
Mature plant ht (in.)	74.4	73.3	72.8	72.4	1.5	<0.01	NS
Final stand (plants/acre × 1 000)	23.0	23.5	23.1	23.3	NS	NS	NS
Grain moisture (%)	22.9	23.1	22.6	23.7	0.8	NS	NS
Grain yield (bu/acre)	126	122	124	127	NS	NS	NS
1988							
Emergence (%)	84.3	84.8	84.9	85.7	NS	NS	NS
Veg. dry wt (oz/10 plants)	1.5	1.3	1.5	1.3	NS	NS	NS
Mature plant ht (in.)	78.3	76.0	76.0	77.5	NS	NS	NS
Final stand (plants/acre × 1 000)	24.6	25.1	24.3	25.1	0.6	NS	0.04
Grain moisture (%)	25.1	26.2	26.0	26.8	NS	NS	NS
Grain yield (bu/acre)	117	110	112	115	NS	NS	NS

† SR = small round, SF = small flat, LR = large round, LF = large flat.
‡ P values for seed size/shape (S) × hybrid (H), and seed size/shape (S) × tillage system (T) interactions.

under NT, but small-round seed had lower emergence under CT than the other combinations (Fig. 1A). In contrast, percent emergence differences occurred under NT, but not under CT at Janesville in 1987 (Fig. 1B). Similar to Arlington the small-round seed had lower emergence than other size/shape combinations when emergence differences occurred at Janesville.

In 1988, seed size/shape differences for percent emergence occurred only at Arlington (Tables 5 and 6), where there were two-way interactions of seed size/shape with planting date and hybrid (Table 5, Figs. 1C and 1D). In 1988 at Arlington, emergence was similar for seed size/shape combinations at the late planting date, but with early planting, small-round and large-flat seed had lower emergence than small-flat seed, and large-round seed was intermediate (Fig. 1C). Averaged over planting dates at this location and year, small-round and large-flat seed of hybrid LH74xLH51 had lower emergence than the other sizes/shapes, but for A632xLH39 emergence of large-round and large-flat seed was lowest, with intermediate values for small-round seed (Fig. 1D). Tillage system by seed size/shape interactions for percent emergence did not occur in 1988 (Tables 5 and 6).

Differences in percent emergence among seed size/shape combinations in various environments are difficult to explain. Although results were inconsistent, differences between sizes/shapes were most likely to occur under stress. For example, differences occurred when soil crusting reduced emergence under CT at Arlington in 1987 (Table 3, Fig. 1A), under NT at Janesville in 1987 (Fig. 1B), and with extremely cold soil following the early (18 Apr.) planting date at Arlington in 1988 (Table 3, Fig. 1C).

When seed size/shape differences in emergence occurred, small-round seed was lowest more often than the other seed size/shape combinations (Fig. 1A-D), although the large-flat seed of hybrid LH74xLH51 had equally low emergence within that hybrid at Arlington in 1988 (Fig. 1D). Pericarp-damage percentage was greatest for small-round and large-flat seed of LH74xLH51 (Table 1), which could explain the low field emergence for these seed sizes/shapes of this hybrid at Arlington in 1988 (Fig. 1D). Although small-round seed often had low emergence, there was no indication that small seed reduced emergence, as small-flat seed consistently had percent emergence levels equal to, or greater than, the average values in any environment (Tables 5 and 6, Figs. 1A–D).

We were careful to select seed with nearly equal cold germination test values (Table 1) in an effort to separate seed vigor from seed size/shape effects. Nonetheless, field emergence differences occurred under stress (Fig. 1A–D). Burris and Navratil (5) did not detect a close relationship between cold germination tests and field emergence when a range of field environments and lab methods were evaluated.

Differences in growth factors other than percent emergence were generally small or inconsistent. Days-to-emergence was not influenced by seed size/shape main effects or interactions except for the main effect at Arlington in 1988 (Table 5), where emergence was slightly delayed with the large-flat seed.

A seed size/shape by hybrid interaction for vegetative dry weight occurred at Arlington in 1987 (Table 5). Vegetative dry weights were similar among seed sizes/shapes for A632xLH39, but large-round seed had slightly higher dry weights than the other seed sizes/shapes for LH74xLH51 (data not shown). The only seed size/shape effect on vegetative dry weight in 1988 occurred at Arlington (Table 5). Small-round and large-round seed had slightly greater vegetative dry weight than small-flat and large-flat seed.

There were seed size/shape effects for days to silking at Arlington in both years but differences were small (Table 5). Small differences between the seed sizes/shapes also occurred for mature plant height at both Arlington and Janesville in 1987 (Tables 5 and 6). Variations in final stand due to seed size/shape occurred in both years at Arlington and in 1987 at Janesville, but the greatest stand differences were less than 4% (Tables 5 and 6).

Grain moisture was influenced by seed size/shape in 1987 at both locations and in 1988 at Arlington (Tables 5 and 6). Generally, seed sizes/shapes that resulted in delayed silking also tended to have higher

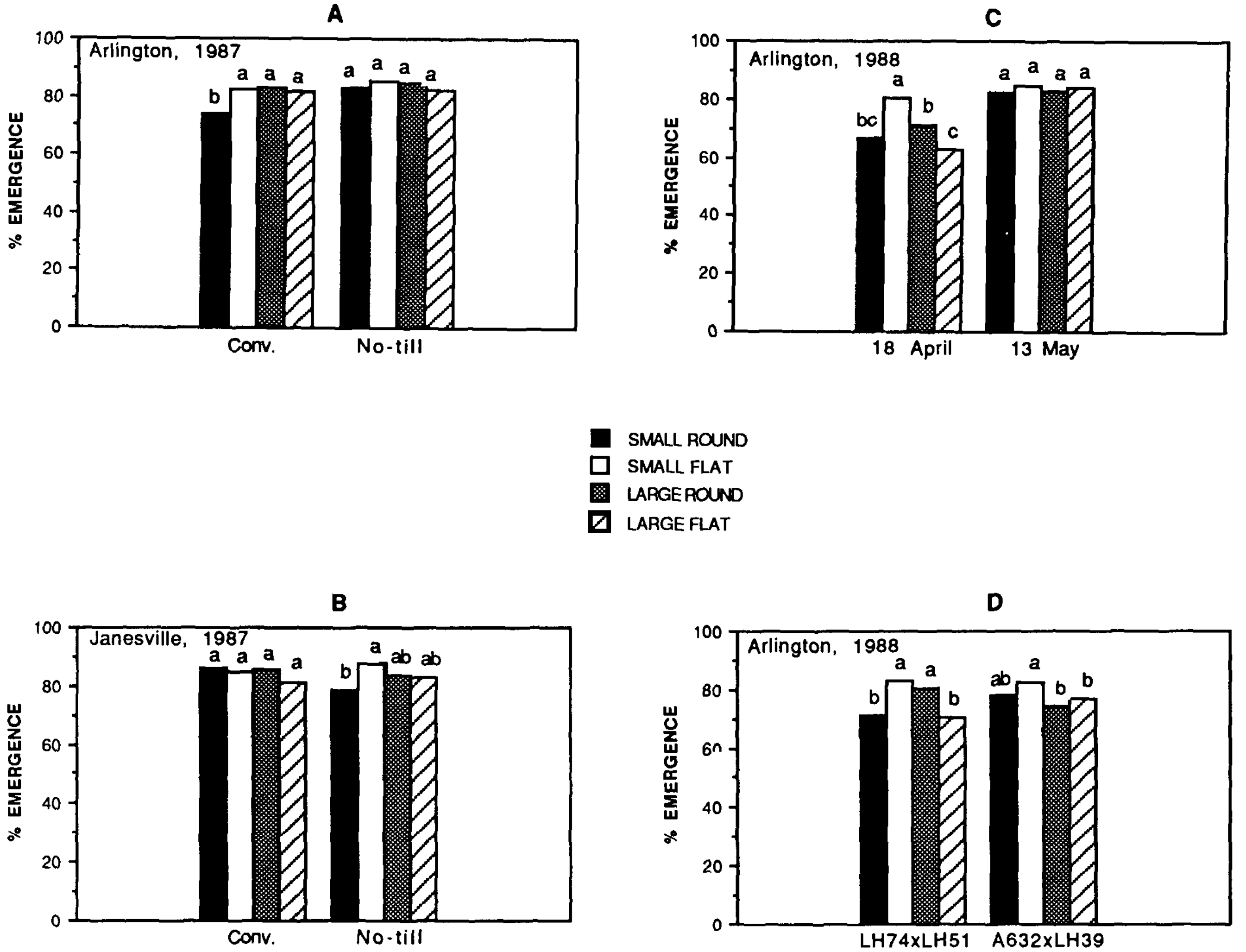

Fig. 1. Percent emergence responses to seed size/shape and tillage system at Arlington (A) and Janesville (B) in 1987 and seed size/shape and planting date (C),and seed size/shape and hybrid (D) at Arlington in 1988. Seed size/shape means represented by bars on the graph for a given tillage system (A and B), planting date (C), or hybrid (D) are not significantly different at P=0.05 according to Fisher's LSD, if the same letter appears above the bar.

grain moisture percentage at harvest (Table 5). A seed size/shape by tillage system interaction occurred at Arlington in 1987 (Table 5) due to small variations in relative grain moisture differences under NT vs. CT for the seed sizes/shapes (data not shown).

Grain yield was not influenced by seed size/shape main effects or two-way interactions in any environment (Tables 5 and 6). Other studies also have shown small, inconsistent seed size/shape effects on growth and yield (4, 9, 11). Previous studies were conducted using older hybrids, conventional tillage, and under less extreme growing environments. Our results indicate that at equal stands, seed size/shape differences within current corn hybrids are not likely to affect grain yield, regardless of planting date or tillage system.

SUMMARY

The results of these studies indicate that any influence of corn seed size/shape on field performance would most likely be due to effects on stand establishment, and not due to subsequent growth factors.

Under stressful conditions, small-round and, less frequently, large-flat seed had lower percent emergence than small-flat and large-round seed. This may be due to increased pericarp injury to the small-round and large-flat seed lots of one of the hybrids evaluated, and could be attributed more to seed handling procedures than to differences in seed size/shape. Although small-round seed had low emergence when differences due to seed size/shape occurred, in all environments small-flat seed had emergence levels equal to, or greater than, the average values.

Emergence rate, vegetative dry weight, silk date, grain yield (at similar stands, accomplished by overplanting and thinning) and other parameters measured were not influenced consistently by seed size/shape. No-till and early planting resulted in cold soil early in the season, which delayed emergence, early growth, and silking. Grain yield was also often reduced under

NT, but tillage system by seed size/shape interactions were not important.

Corn producers should focus on genetic potential, seed quality, and seed price rather than a specific seed size/shape combination when selecting hybrids, except when planting under stressful conditions. Our results suggest that under extremely early planting or NT it may be advisable to avoid small-round seed, or to increase seeding rate by 10 to 15% with this seed size/shape in order to obtain the desired stand. Additional research evaluating sizes/shapes with more hybrids using seed grown in the same year and field, and with the same drying, conditioning, and storage environment is needed to determine whether the decreased percent emergence of small-round seed in our studies is generally representative of seed available to corn producers.

ACKNOWLEDGMENTS

This research was supported partially by a grant from Pioneer Hi-Bred International, Inc. We also would like to acknowledge the following firms for providing seed used in these studies: Carhart's Blue Top Seed, Inc.; Jung Farms, Inc.; Kaltenberg Seed Farms, Inc.; Lemke Seed Farms, Inc.; O'Brien Farms, Inc.; and Spangler Brothers, Inc. We thank Eugene Amberson, Wisconsin Crop Improvement Association, for advice regarding seed analysis and use of facilities.

REFERENCES

1. Al-Darby, A.M., and B. Lowery. 1986. Evaluation of corn growth and productivity with three conservation tillage systems. Agron. J. 78:901–907.
2. Association of Official Seed Analysts. 1983. Seed vigor testing handbook. AOSA Handb. Contr. no. 32:1–88.
3. Association of Official Seed Analysts. 1986. Rules for testing seeds. J. Seed Technol. 6:1–126.
4. Burris, J.S., D.R. Hicks, and J. Wikner. 1984. Seed corn quality and size. Purdue Univ. Coop. Ext. Serv. NCH-16.
5. Burris, J.S., and R.J. Navratil. 1979. Relationship between laboratory cold-test methods and field emergence in maize inbreds. Agron. J. 71:985–988.
6. Carter, P.R., and K.H. Barnett. 1987. Corn hybrid performance under conventional and no-tillage systems after thinning. Agron. J. 79:919–926.
7. Dickey, E.C., P.J. Jasa, and D.P. Shelton. 1986. Estimating residue cover. Univ. of Nebraska Coop. Ext. Serv. G86-793.
8. Gill, N.S., and J.C. Delouche. 1973. Deterioration of seed corn during storage. Proc. Assoc. Off. Seed Anal. 63:33–49.
9. Hicks, D.R., R.H. Peterson, W.E. Lueschen, and J.H. Ford. 1976. Seed grade effect on corn performance. Agron. J. 68:819–820.
10. Hoppe, P.E. 1955. Cold testing seed corn by the rolled towel method. Wisconsin Agric. Exp. Stn. Bull. 507:1–6.
11. Hunter, B.R., and L.W. Kannenberg. 1972. Effect of seed size on emergence, grain yield and plant height in corn. Can. J. Plant Sci. 52:252–256.
12. Imholte, A.A., and P.R. Carter. 1987. Planting date and tillage effects on corn following corn. Agron. J. 79:746–751.
13. Kiesselbach, T.A. 1937. Effects of age, size and source of seed on the corn crop. Nebraska Agric. Exp. Stn. Bull. 305.
14. Koehler, B. 1957. Pericarp injuries in seed corn. Univ. of Illinois Agric. Exp. Stn. Bull. 617.
15. Meyers, M.T. 1924. The influence of broken pericarp on the germination and yield of corn. J. Am. Soc. Agron. 16:540–550.
16. Munchena, S.C., and C.O. Grogan. 1977. Effects of seed size on germination of corn (*Zea mays*, L.) under simulated water stress conditions. Can. J. Plant Sci. 57:921–923.
17. Ritchie, S.W., J.J. Hanaway, and G.O. Benson. 1986. How a corn plant develops. Iowa State Univ. Coop. Ext. Serv. Spec. Rep. no. 48.
18. Swan, J.B., E.C. Schneider, J.F. Moncrief, W.H. Paulson, and A.E. Peterson. 1987. Estimating corn growth, yield, and grain moisture from air growing degree days and residue cover. Agron. J. 79:53–60.
19. Tatum, L.A., and M.S. Zuber. 1943. Germination of maize under adverse conditions. J. Am. Soc. Agron. 35:48–59.
20. Wisconsin Crop Improvement Association. 1984. Wisconsin seed certification standards. Madison, WI 53706.
21. Wych, R.D. 1988. Production of hybrid seed corn. p. 565–607. *In* G.F. Sprague and J.W. Dudley (ed.) Corn and corn improvement. 3rd ed. Agronomy Monogr. 18. ASA, CSSA, and SSSA, Madison, WI.