CORN RESPONSE TO WITHIN ROW PLANT SPACING

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Key planting factors that influence corn stand establishment includes uniform depth and spacing of seed, correct seed population and optimizing the soil environment for rapid germination and uniform emergence. Other variables affecting stand establishment are seedbed quality (including soil moisture and temperature), seed quality and planter speed. Differences among fields for stand establishment are usually not due to any single factor rather it is a combination of factors during the planting operation that lead to inconsistent stands.

Several factors influence a plant's ability to compete among individuals within a plant community. Agronomic production of crops usually involves homogeneous individuals that theoretically compete equally for resources so that exclusion at the community level rarely occurs. Yet, variation exists, especially for yield, the ultimate measure and integrator of a plant's ability to compete for resources. Some variation can be traced to plant density, plant spacing relative to neighbors, time of emergence, and developmental setbacks due to pests and weather. There are three types of plant spacing variation usually observed in the field alone and in combination. First is *spacing variation at the same population*. This is usually observed from after planting with an improperly setup planter. Second, is *spacing variation from reduced population*. This is typically observed in commercial production fields where less seed is planted than originally thought. Finally, excessive planting speed, crusting, "thickening-up" of stands, dry soils, etc. can cause *temporal variation*. This latter type of variation may be most important in the field.

There is much recent interest in the grain yield response of corn to plant spacing variability. Many companies are offering planter "tuning" services. Some seed company agronomists have estimated yield losses of between 5 and 10 bu/A in corn stands with non-uniform spacing. Various advertisements in trade publications have claimed yield increases up to 20% with a well-tuned planter.

One question often asked is how much variation can be tolerated before yield and crop profitability is affected? Research reports are mixed regarding corn response to variation of within row plant spacing. Early research on plant spacing variability indicated little response to yield even when planted in hills (Kiesselbach et al., 1935 as reported by Dungan et al., 1958). In Iowa, found no significant yield impacts up to 6 inches standard deviation (Erbach et al., 1986). Similar results were observed in Ontario ((Muldoon and Daynard, 1981), Illinois (Johnson and Mulvaney, 1980) and Indiana ((Nielsen, 1995) However, Nielsen (web) later stated that grain yield decreases 2.5 bu/A for each inch standard deviation greater than 2 inches.

Other research indicates that plants pacing significantly reduces grain yield. In Kansas, (Krall et al., 1977) found a 3.4 bu/A decrease for each inch increase in standard deviation and (Vanderlip et al., 1988) found that grain yield decreased when standard deviation values were greater than 2.4 inches.

Most farmers and agronomists agree that uniform stand establishment is ideal and can only be achieved by a well-calibrated planter and sound agronomic practices. Our objective was to measure the response of corn to plant spacing variation and to determine at what point that stand spacing variation influenced yield.

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MATERIALS AND METHODS

Experiment 1

A preliminary experiment was conducted during 1999 at the University of Wisconsin Agricultural Research Station near Arlington, Wisconsin. The soil was a Plano silt loam (fine-silty, mixed, mesic Typic Argiudoll). Management practices were typical of those utilized commercially in many dryland fields in the Corn Belt of the Midwestern United States.

Pre-plant soil samples from 0 to 15 cm depth were analyzed for residual nutrient levels. Soil was sampled from a field where the previous crop was soybean, *Glycine max* Merrill. Soil test results were organic matter: 3.1 %, pH: 6.8, P: 45 ppm, and K: 240 ppm. A total of 159 pounds N A^{-1}, 36 pounds P_2O_5 A^{-1} and 36 pounds K_2O A^{-1} fertilizer was applied. On 23 April 1999, urea (46-0-0) was broadcast pre-plant and immediately incorporated. On 10 May 1999 starter fertilizer (6-24-24) was applied 2x2 at planting. The soil in the study area was prepared for seeding by fall chiseling and soil finishing. On 10 May 1999, a Kinze planter was used to seed 'Cargill 4111' hybrid corn at a rate of 90,000 seeds A^{-1} in furrows 1.5 inches deep in rows 30 inches apart. Weeds were controlled pre-emerge using the herbicides Frontier and Bladex at the rate of 1.5 + 2.2 pints A^{-1}. In addition, plots were hand weeded to control escape weeds. Plots were harvested on 18 October 1999 with a two row Kincaid plot combine.

The experimental design was a randomized complete block (4x4 factorial) with three replications. Factors were target harvest plant densities of 10,000, 20,000, 30,000 and 40,000 plants A^{-1} and 2-plant pattern spacing standard deviations of 1, 2, and 3 inches. The controls were treatments of target harvest plant densities at 10,000, 20,000, 30,000 and 40,000 plants A^{-1} with zero standard deviation. Plots were four rows wide and measured 25 feet long. Plots were hand-thinned to target harvest plant densities and plant spacing standard deviations at V6.

Experiment 2

The experimental design was a randomized complete block with three replications. Treatments were target harvest plant densities of 15,000 with 2-plant pattern spacing standard deviations of 0, 4, 8, and 12 inches and 30,000 plants A^{-1} with 2-plant pattern spacing standard deviations of 0, 1, 2, 3, 4 and 5 inches. Plant arrangements for the plant density treatments of 30,000 plants A^{-1} are shown in Figure 1. The controls were treatments of target harvest plant densities at 15,000 and 30,000 plants A^{-1} with zero standard deviation. Plots were four rows wide and measured 25 feet long. Plots were hand-thinned to target harvest plant densities and plant spacing standard deviations.

Experiment 3

The experimental design was a randomized complete block with three replications. Treatments were target harvest plant density of 30,000 plants A^{-1} with 2-plant pattern spacing standard deviations of 2 and 4 inches; 4-plant pattern spacing standard deviations of 2, 4, and 8 inches; and 8-plant pattern spacing standard deviations of 2, 4, 8 and 12inches (Figure 1). The control was a treatment of a target harvest plant density of 30,000 plants A^{-1} with zero standard deviation. Plots were four rows wide and measured 25 feet long. Plots were hand-thinned to target harvest plant densities and plant spacing standard deviations.

Experiment 2 was conducted during 1999 and experiment 3 was conducted during 2000. In each year a total of 10 locations in Wisconsin were established. Management practices were similar to those described above in Experiment 1 and typical of those utilized commercially in many dryland fields in the Corn Belt of the Midwestern United States. The corn hybrids 'Pioneer 35R57' was planted at Arlington, Janesville, and Lancaster, 'Cargill 4111' was planted at Fond du Lac, Galesville, and Hancock, and 'NK Brand 3030Bt' was planted at Chippewa Falls, Marshfield, Seymour, and Valders.

In each experiment, treatment mean comparisons were made using least significant difference when *F* values were significant ($P \leq 0.05$). The chi-square test (Gomez and Gomez, 1984) was used to verify homogeneity of variance in order to combine experiments.

RESULTS AND DISCUSSION

The amount of plant spacing standard deviation is a function of the plant density. With lower plant density, greater plant spacing standard deviation can be found since there is more space between plants. As plant density increases less space is available between plants. The only way to increase the amount of available space for spacing standard deviation and not affect plant density is to arrange plants into hill patterns of 2-, 4-, and 8-plant patterns (Figure 1).

In all experiments, plant spacing standard deviation had no effect ($P \leq 0.05$) on grain moisture, lodging and grain test weight (Tables 1, 2, 3 and 4), with the only exception for grain moisture in the 30,000 plants A^{-1} treatment at Galesville in 1999 (Table 2).

Plant density was significantly affected by treatment at Seymour for the 30,000 plants A^{-1} treatment in 1999 (Table 2), Arlington and Janesville for the 15,000 plants A^{-1} treatment in 1999 (Table 3), and Arlington, Janesville, and Marshfield in 2000 (Table 4). Even though significance was observed, all of the treatment populations were within 1500 plants A^{-1} of each other indicating that yields would be affected at most by about 2%.

It was difficult to establish the target plant spacing standard deviation treatments, especially the control treatment. The control plots with a target of zero plant spacing standard deviation ranged from 2.2 to 3.6 inches at harvest depending upon the experiment (Figures 1, 2 and 3) even though they were seeded at 3x the target plant density.

Significant differences among plant spacing standard deviation treatments were observed at all locations, except in Arlington - Experiment 1 (Table 1) and the 30,000 plants A^{-1} treatment at Lancaster in 1999 (Table 2), although $P \leq 0.10$ in each case. This indicates that plant spacing standard deviation treatments were successfully applied.

Plant spacing standard deviation significantly affected grain yield at Fond du Lac in 1999 and 7 of 10 locations in 2000, with exceptions being Janesville, Lancaster and Chippewa Falls. In Experiment 1 no significant corn yield response was observed due to differences in plant spacing standard deviation (Table 1 and Figure 2). Yield differences observed in this study were due to plant density differences between treatments rather than plant spacing standard deviation.

Similar results were observed for the 2-plant pattern treatments in Experiment 2 (Figure 3). Yield differences were due to plant density differences between treatments rather than plant spacing standard deviation.

In Experiment 3 treatments involving 4- and 8-plant patterns that had plant spacing standard deviation treatments greater than 5 to 7 inches affected grain yield (Figure 4). Grain yield was not affected from that of the control when all plant patterns had plant spacing standard deviation less than 5 inches, but grain yield was reduced between 5 and 18% when plant spacing standard deviation was greater than 5 inches.

The greater impact on grain yield in these studies was due to plant density rather than plant spacing variation. Averaged across all environments, no significant relationship was measured between grain yield and plant spacing standard deviation where plant densities were similar, except when obvious gaps where present in the stand and plants were arranged in 4- and 8-plant patterns.

In light of these results, do planters still need to be tuned? Agronomists should never recommend not going through and tuning a planter because it provides “peace of mind” and planter problems can be corrected before the planting season begins. However, the corn plant can compensate dramatically to variations in plant spacing as long as plant density is adequate for the field. What might be more important is temporal variation for time of emergence. Temporal and seeding depth variation in corn stands needs to be further researched.

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Table 1. Tests of significance for measurements for plant density and plant spacing variability treatments during 1999 at Arlington, Wisconsin. (Experiment 1)

Factor	Plant density	Plant standard deviation	Grain yield	Grain moisture	Lodging	Grain test weight
Plant density	**	**	**	**	**	**
Plant standard deviation	NS	†	NS	NS	NS	NS
PD x PSD	NS	NS	†	*	NS	NS

**, *, and † indicates significance at $P < 0.01$, 0.05 and 0.10, respectively

Table 2. Tests of significance for measurements of plant spacing variability treatments for a plant density of 30,000 plants/A at 10 locations in Wisconsin during 1999. (Experiment 2)

Location	Plant density	Plant standard deviation	Grain yield	Grain moisture	Lodging	Grain test weight
Arlington	NS	**	NS	NS	NS	NS
Janesville	NS	**	NS	NS	NS	NS
Lancaster	†	†	NS	NS	NS	NS
Fond du Lac	NS	*	*	NS	NS	NS
Galesville	NS	*	NS	*	NS	NS
Hancock	NS	*	NS	NS	NS	NS
Chippewa Falls	NS	**	NS	NS	NS	NS
Marshfield	NS	*	NS	NS	NS	NS
Seymour	*	**	NS	NS	NS	NS
Valders	NS	**	NS	NS	NS	NS

**, *, and † indicates significance at $P \leq 0.01, 0.05$ and 0.10, respectively

Table 3. Tests of significance for measurements of plant spacing variability treatments for a plant density of 15,000 plants/A at 10 locations in Wisconsin during 1999. (Experiment 2)

Location	Plant density	Plant standard deviation	Grain yield	Grain moisture	Lodging	Grain test weight
Arlington	*	**	NS	NS	NS	NS
Janesville	NS	**	NS	NS	NS	NS
Lancaster	**	**	NS	NS	NS	NS
Fond du Lac	NS	**	NS	NS	†	NS
Galesville	NS	**	†	NS	NS	NS
Hancock	NS	**	NS	NS	NS	NS
Chippewa Falls	NS	**	NS	NS	NS	NS
Marshfield	NS	**	NS	NS	NS	†
Seymour	†	**	*	NS	NS	NS
Valders	†	**	NS	NS	NS	NS

**, *, and † indicates significance at $P \leq 0.01, 0.05$ and 0.10, respectively

Table 4. Tests of significance for measurements of plant spacing variability treatments for a plant density of 30,000 plants/A at 10 locations in Wisconsin during 2000. (Experiment 3)

Location	Plant density	Plant standard deviation	Grain yield	Grain moisture	Lodging	Grain test weight
Arlington	**	**	**	NS	†	NS
Janesville	**	**	NS	NS	NS	NS
Lancaster	†	**	†	NS	NS	NS
Fond du Lac	†	**	*	NS	NS	NS
Galesville	NS	**	**	NS	NS	NS
Hancock	†	**	**	NS	NS	†
Chippewa Falls	†	**	NS	NS	†	NS
Marshfield	**	**	**	NS	NS	NS
Seymour	NS	**	**	NS	NS	NS
Valders	NS	*	**	NS	NS	NS

**, *, and † indicates significance at $P \leq 0.01, 0.05$ and 0.10, respectively

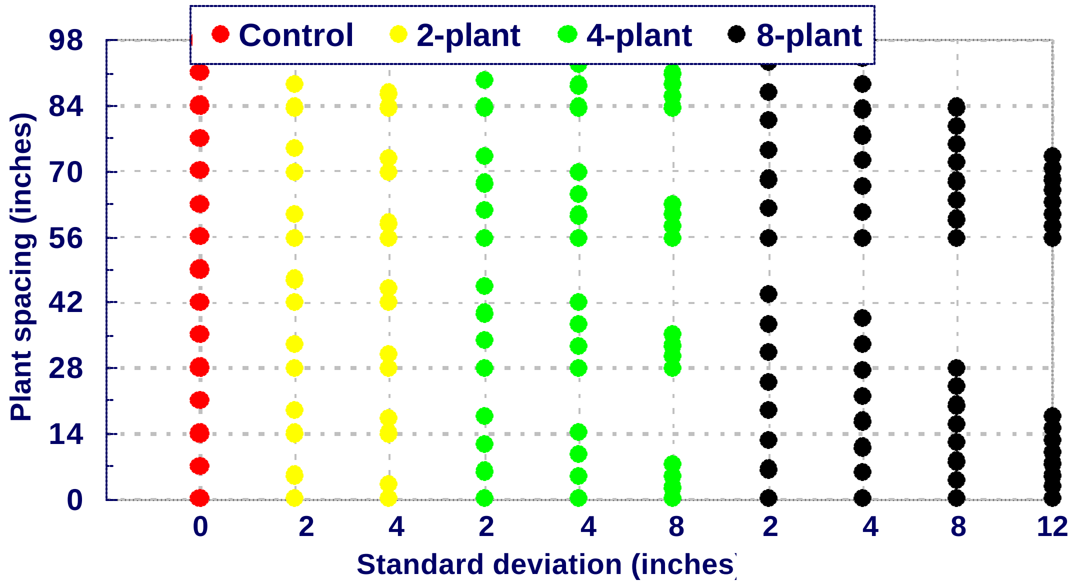

Figure 1. Target plant spacing variability treatments for 2-, 4-, and 8-plant patterns in a plant density of 30,000 plants/A. The control is zero standard deviation.

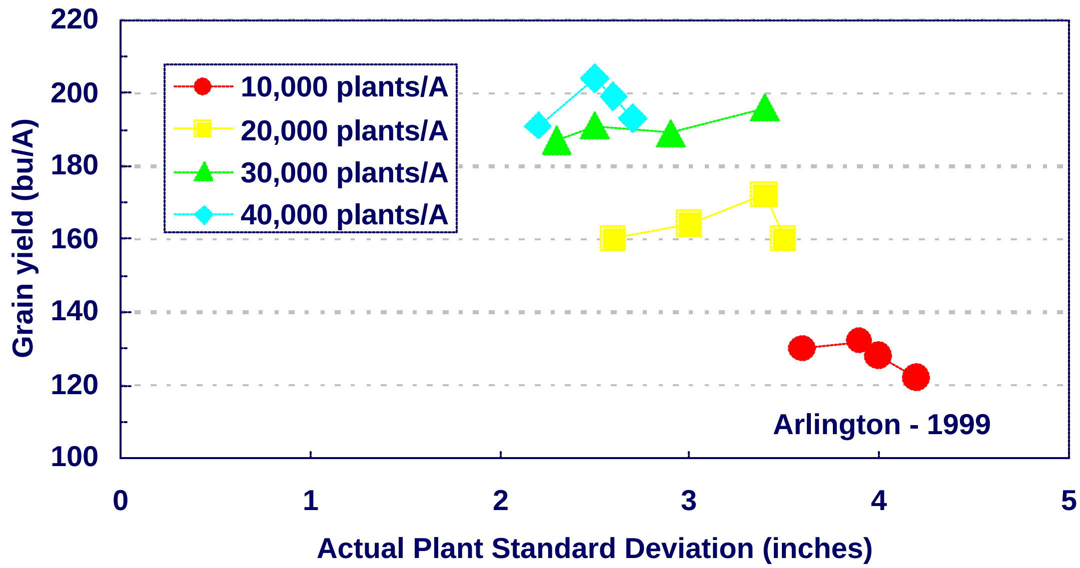

Figure 2. Corn yield response to plant spacing variation in various plant densities.

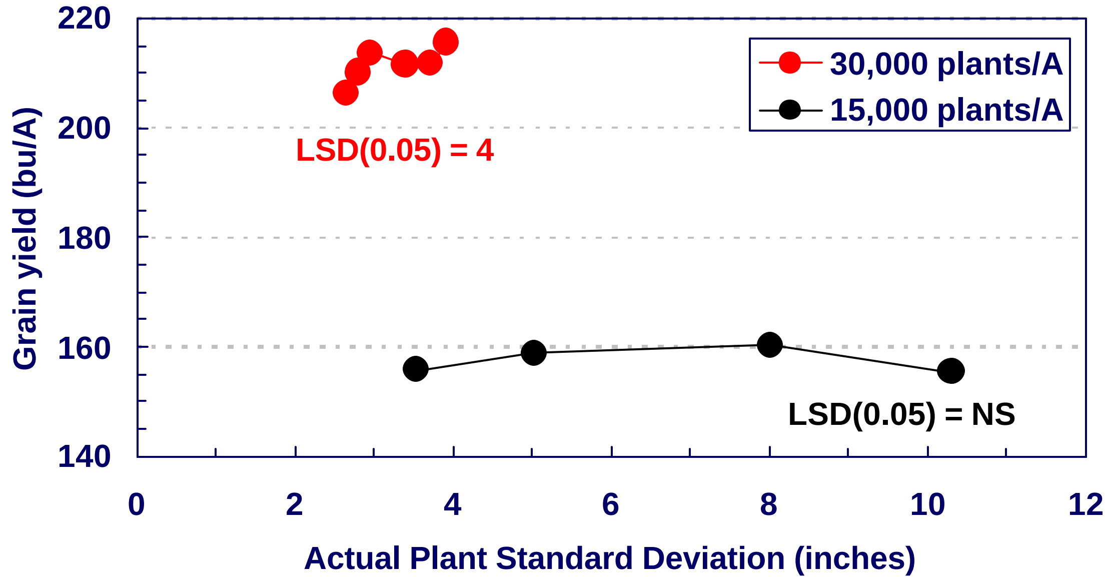

Figure 3. Corn yield response to plant spacing variability treatments during 1999. Values are averaged across all locations.

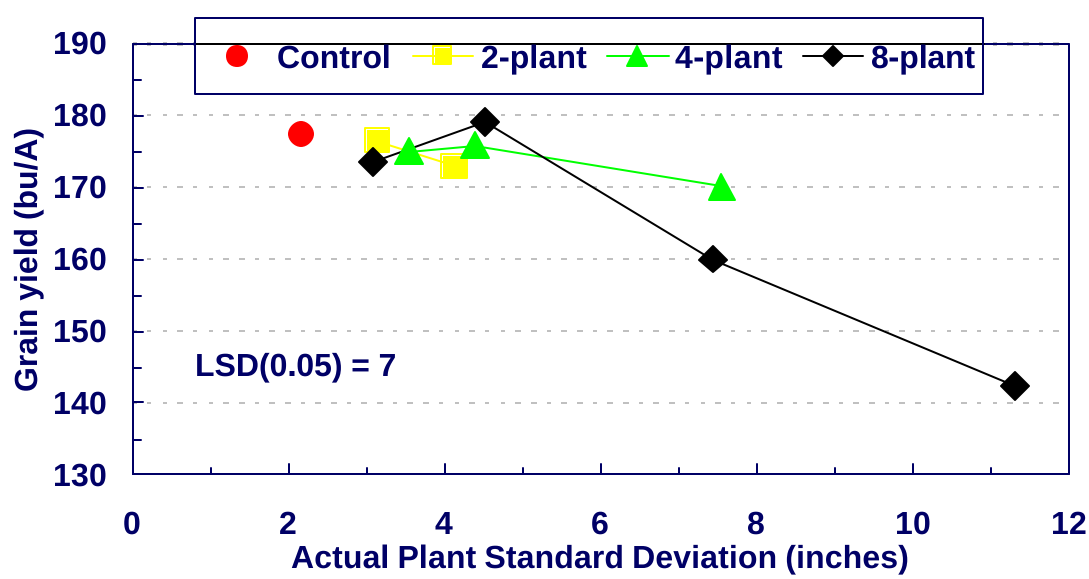

Figure 4. Corn yield response to plant spacing variation involving 2-, 4-, and 8-plant patterns during 2000. Values averaged across all locations.