STAND ESTABLISHMENT VARIABILITY IN CORN

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Background

Uniform stand establishment in corn is an intuitively important criterion for setting the stage for maximum grain yield. Uneven stands may be described in terms of plant-to-plant variability for spacing within the row, time of seedling emergence, and/or eventual growth and development.

Plant spacing variability (**PSV**) can be described by the standard deviation (**SD**)[1] of consecutive plant-to-plant spacings within rows. Field survey data collected from 354 fields in Indiana and Ohio during 1987-1996 suggested that the average commercial field of corn had an SD of about 4.5 inches and ranged from slightly less than 2.5 inches to more than 10 inches (Figure 1).

Lauer and Rankin (2004) surveyed 127 fields in Wisconsin from 1998-2000 for plant population and plant spacing variability. They reported an average SD of 3.3 inches with a range of 1.9 to 6.8 inches. Furthermore, 95% of the fields surveyed had an SD less than 4.6 inches.

I first investigated the effects of PSV on corn grain yield in the late 1980s and early 1990s (Nielsen, 1991). The results of that field research suggested that yield loss due to uneven plant spacing averaged 2.5 bushels per acre (**bpa**) per inch increase in SD of plant spacing. The magnitude of yield loss observed over eight site-years ranged from 1.2 to 4.5 bpa per inch of SD.

Research results published by Pioneer Hi-Bred International from studies conducted in 2001, documented similar effects of plant spacing variability on corn grain yield, with reported yield losses due to PSV averaging 3.4 bpa per inch of SD (Doerge et al., 2002).

To be fair, not all research on the effects of uneven plant spacing has supported the conclusions made by yours truly or Doerge et al. (2002). Most everyone agrees that gaps within rows that not only cause higher plant spacing variability but also dramatically lower overall plant populations will typically lead to lower corn grain yields. Conversely, Nafiziger (1996) concluded that the net effect of double seed drops on grain yield may actually be positive up to some undefined upper threshold of plant population.

The disagreement occurs over the net effect of mixtures of gaps and crowded plants in a field, especially when the resulting plant population is within the range considered to be optimum for corn grain yield (28,000-32,000 plants per acre). More recently, two separate papers published in 2004 concluded that the effects of plant spacing variability on corn grain yield were negligible in studies conducted in Wisconsin (Lauer and Rankin, 2004) and Ontario, Canada. (Liu et al., 2004a). Conversely, subsequent research published by the Ontario research group identified a significant linear yield loss due to uneven plant

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[1]**NOTE:** The standard deviation is a common statistical calculation used to describe variability within a set of values. In this case, it is used to represent the variability among consecutive plant-to-plant spacings within rows of a cornfield. Most computer spreadsheet programs can calculate the standard deviation of a group of values (i.e., a given range of data cells) with the use of a built-in mathematical function. For example, in Microsoft Excel the formula would be: =STDEV(cell range).

spacing equal to 1.5 bpa per inch of SD in a study that evaluated the effects of planting speed on stand uniformity (Liu et al., 2004b).

In light of these recent research reports, I decided to "resurrect" my own research in 2004 to re-evaluate the effects of uneven plant spacing on corn grain yield. Hybrids have changed and seeding rates have generally increased since I last studied this issue in the late '80s and early '90s, so there was indeed a possibility that the effects of plant spacing variability were different today. An ulterior motive for resurrecting the study was a desire to investigate this issue in larger-scale field plots rather than the traditional small-plot studies I conducted years ago.

Current Research

In the research I conducted in the late '80s and early '90s, I created repeatable levels of PSV by plugging cells of seed discs of an air planter in pre-determined patterns and modifying the planter transmission setting accordingly to plant the desired target seeding rate. For the current study, with the collaborative assistance of Case IH engineers and agronomists, five sets of seed discs for use with a Case IH 1200 ASM air planter were custom-engineered with distinctive patterns of 20 seed cell positions that would create predictable planting patterns of crowded seeds and gaps. The targeted PSV treatments resulting from the planted seed, when combined with a specific planting speed (4 mph) and seed disc revolution (35 rpm), were SD of 0-, 2-, 4-, 6-, and 8-inches.

Prototype PSV treatment seed discs were tested at Case IH's Burr Ridge, IL, engineering facility to verify that the actual seed drop patterns matched the predicted patterns. Following the successful completion of these tests, four complete sets of PSV treatment seed discs were manufactured to accommodate an 8-row Case IH 1200 ASM planter. An additional set of seed discs was manufactured with 20 equally spaced seed cells that were used to plant the control treatments with a targeted SD equal to zero.

The targeted seeding rate for all of the intended PSV treatments was 34,848 seeds per acre (**spa**), which translates to an average plant-to-plant spacing of 6 inches. Because of physical seed spacing limitations on the seed disc, the closest mimic of a double seed drop that was achievable was a planted seed spacing of 2 inches. The predicted frequency distributions of plant-to-plant spacings for the five targeted PSV patterns are illustrated in an earlier published research update (Nielsen, 2004).

A 107-day relative maturity hybrid with fixed ear size characteristics and the YieldGard Bt-Rootworm trait (Diener 1076RW) was selected for the 2004 trial. A second Bt-rootworm hybrid of similar relative maturity, but differing for ear size determination characteristics (Diener 1065RW, flex-ear), was added to the 2005 and 2006 trials. Both hybrids were also treated with Poncho 250 seed-applied insecticide for protection against secondary soil insects.

Predicting how each hybrid might respond to PSV was not clear-cut. One could argue that a hybrid whose ear size is truly non-responsive to plant density ("fixed" ear characteristic) may not respond at all to uneven plant spacing. One could also argue that a hybrid whose ear size is strongly "flex" (responsive to plant density) may also not respond to equal mixtures of gaps and crowded plants if the negative "flex" response due to crowded plants within the row offsets the positive "flex" response surrounding gaps within the row. Alternatively, if the positive "flex" response surrounding gaps was greater than the negative "flex" due to crowded plants, a flex-ear hybrid may respond positively to uneven plant spacing. Finally, if the positive "flex" surrounding gaps was less than the negative "flex" due to crowded plants, a flex-ear hybrid may respond negatively to uneven spacing.

Large-scale field trials were established at one or more of five outlying Purdue research facilities each year: Pinney-Purdue Agricultural Center (PPAC) located in northwest Indiana near Wanatah, Northeast Purdue Ag. Center (NEPAC) in northeast Indiana near Columbia City, Davis-Purdue Ag. Center (DPAC) in east-central Indiana near Farmland, Southeast Purdue Ag. Center (SEPAC) in southeast Indiana near North Vernon, and Throckmorton-Purdue Ag. Center (TPAC) in west-central Indiana near Lafayette. Field sizes, previous crop, and tillage practices for the site-years are listed in Table 1. The 2006 NEPAC site was abandoned due to extremely poor emergence in response to 11 days of saturated soils following planting of that site on May 9. A fifth site was intended to be established in 2006 at TPAC, but was not planted due to frequent spring rains and the prospect of planting being delayed into early June.

At each location, the two hybrids and five PSV treatments were replicated in a split-plot layout arranged in a randomized complete block design. Hybrids were assigned as the main plot treatments and PSV levels were the subplot treatments within a hybrid. The exact planting layout for each trial was designed with the aid of GIS software and previously acquired geo-referenced field boundaries.

Each subplot was eight 30-inch rows (20 feet) by length of field (350 to 1,400 ft) with the intent of harvesting the center six rows. End rows and bulk areas of each field were planted to a non-Bt hybrid in accordance with EPA regulations for the establishment of Insect Refuge Management areas for Bt-rootworm hybrids.

The trials were planted from mid-April through late May with an 8-row Case IH 1200 ASM planter at a targeted seeding rate of 34,848 spa and a targeted seeding depth of 2 inches (Table 1). The Case IH 7200 tractor was equipped with a Trimble EZ-Steer assisted steering system (and OmniStar HP DPGS signal) that facilitated the planting of all replicates of a hybrid-PSV treatment combination (randomized throughout the field) with minimal plot flagging or other physical plot identification. Actual seeding rate and depth were verified in buffer plots prior to planting treatment plots.

Neither planter-applied insecticide nor starter fertilizer was used for these trials. Nitrogen fertilizer (28% UAN) was either preplant-applied (TPAC) or sidedress-applied (DPAC, NEPAC, PPAC, and SEPAC) at rates appropriate for the yield history of the field. Chemical weed control programs were implemented as appropriate for the tillage system and predominant weed species of each field.

Prior to the V6 stage of plant development, plant-to-plant spacings were recorded for all plants within 25 linear feet of row for each of two subsamples per plot. The average standard deviation and plant population were subsequently calculated for each plot.

The five trials were harvested (center six rows of each plot) from late September through mid-October (Table 1) with commercial combines equipped with AgLeader PF3000 Pro yield monitors and DGPS receivers. Grain moisture contents of subsamples taken during combine unloading were determined with a DICKEY-john GAC2100 Agri moisture meter (GAC2000 at SEPAC) and used for calibrating the grain moisture estimates made by the combine's grain moisture sensor. Calibration loads representing each hybrid and PSV level were harvested and weighed with commercial scales or weigh wagons and used to calibrate the wet weight estimates by the yield monitor, resulting in yield monitor estimation error rates less than 0.5%. Grain weights and moisture contents for the remainder of the plots were recorded solely by the yield monitor and downloaded to a handheld computer at the completion of the day's harvest.

The yield data were initially processed via AgLeader's SMS Basic software using antenna front offsets and grain flow shifts appropriate for each location's combine. Processed yield data were exported as plain text files in AgLeader Advanced File Format. The exported yield files were imported into ArcView GIS software for further data cleaning and assignment of plot identifications. No less than 50 feet of yield data were deleted from each end of the combine harvest passes to minimize the usual “ramp up” and “ramp down” yield monitor effects that occur at the beginning and end of the yield monitor data for each plot. Where justified, additional yield data were deleted based on recorded field features (waterways, wet holes, animal damage, etc.) or combine problems (plugged stalk rolls, rocks, etc.) previously identified by geo-referenced crop scouting or notes taken during plot harvest.

Analyses of variance of the datasets were conducted with the aid of SAS-Stat software v8.2 (SAS Institute Inc., Cary, NC, USA). Where the analysis indicated statistically significant treatment effects, least significant difference (LSD) values were calculated at a 10% probability of error level and used for treatment mean comparisons. Simple linear regression was used to describe the relationship between PSV and yield.

Results

The custom-engineered planter seed discs did what they were designed to do: create repeatable treatment levels of plant spacing variability. The actual (measured) standard deviations of plant spacing for each targeted PSV treatment level tended to be greater than what was predicted at the onset of the trial although there was very close agreement between targeted and actual SD for the three largest SD treatments (examples from 2005 listed in Table 2). The greatest discrepancy between targeted and actual SD occurred with the zero SD (control) treatments. Even though seed singulation with the control treatment seed disc may have been perfect, subsequent movement of the seed from the seed meter to the furrow introduces some minimal level of spacing variability. Similar results were observed with the zero SD seed discs when tested in the laboratory prior to the study (Nielsen, 2004).

Final plant populations across all nine site-years averaged about 94% (32,873 plants per acre) of the targeted seeding rate and were statistically similar among the five targeted PSV treatments. Except for Pinney 2005, correlations between actual PSV and plant population on a per plot basis were non-significant, though significant at Pinney, the magnitude of the correlation was relative low. The similarity of final stands among the PSV treatments was exactly what was intended in order to avoid any confounding yield effects of uneven plant spacing with those of unequal plant populations.

Grain yields were excellent at six of the seven locations harvested as of October 17, 2006, but below average at PPAC (northwest Indiana) in 2005 where serious moisture deficits existed throughout the growing season (Table 3). While yields at the other six locations were very good, each location experienced periods of stressful moisture deficits of varying lengths sometime during the season. Additionally, significant rainfall shortly after planting at TPAC 2005 caused some silting over of the planted rows and subsequent uneven seedling emergence. Spatial yield variability within most of the experimental fields was quite large, although not unusual for each field’s combinations of soil types, drainage patterns, and elevation variability.

Grain yields varied significantly ($P \leq 0.10$) among the five PSV treatments at all seven locations, with the greatest yields generally occurring with the more uniformly spaced treatments and lowest yields occurring with the least uniformly spaced treatments (Table 3). The exception was at SEPAC where all of the TPSV treatments yielded similarly except for the 2-inch TPSV treatment.

Significant ($P \leq 0.10$) negative linear relationships were identified between corn grain yield and actual (measured) SD of plant spacing at six of the seven locations in this trial (Table 4). The average rate of yield loss for the six responsive sites was 1.7 bpa per inch increase in SD of plant spacing. While significant, the observed range of rates of yield loss per inch of SD (0.8 to 2.1 bushels per acre [bpa]) were less than the average loss rate measured in my original studies over 15 years ago (2.5 bpa) and by Doerge et al. in their 2002 report (3.4 bpa); but were similar to the 1.5 bpa reported more recently by Liu et al. (2004).

The interaction between the two hybrids and targeted PSV treatments was significant ($P \leq 0.10$) at three of the seven site-years (harvested as of October 17, 2006). This interaction was of interest because the two hybrids were chosen primarily for their advertised differences in ear size determination ("flex" versus "fixed") characteristics and, thus, possible differences in grain yield response to uneven plant spacing. The fixed-ear 1076RW was the single hybrid used in the 2004 preliminary trial at PPAC (Nielsen, 2004).

As it turns out, there was no consistent hybrid difference among the three locations where the Hybrid × PSV interaction term was significant. Grain yield of the fixed-ear hybrid at DPAC 2005 decreased at a greater rate in response to uneven plant spacing than did the flex-ear hybrid. The opposite occurred at the PPAC 2005 location where the fixed-ear hybrid did not respond at all to uneven spacing. At TPAC 2005, neither hybrid responded linearly to increasing levels of PSV.

Conclusions

The average rate of yield loss for the six responsive sites was 1.7 bpa per inch increase in SD of plant spacing within a range of plant spacing SD of about 2 to 8 inches. Results from these field trials support those observed more than 15 years ago over eight site-years using different hybrids and lower seeding rates (Nielsen, 1991). They also agree (albeit at different loss rates) with more recent results published by Doerge et al. (2002), and Liu et al. (2004). The two hybrids selected for the 2005-06 trials to represent opposite ear size determination characteristics did not differ consistently in their response to uneven plant spacing.

Guidelines

The good news about uneven plant spacing is that the problem often lies with the planter itself. Common sense planter maintenance and adjustments during planting often correct or avoid the majority of the problems with seed drop variability. The first step in improving plant spacing uniformity, though, is to accurately diagnose the nature of the plant spacing problem.

Uneven plant spacing that is due primarily to crowded plants (e.g., double or triple seed drops) is likely a true planter problem. Large skips or gaps within the row may be planter-related or may be due to seed/seedling mortality issues (e.g., soilborne insects, diseases, saturated soils). Mixtures of crowded plants and gaps in the row (plus a final stand close to your targeted seeding rate) likely signal planter problems.

Several seed companies, plus a number of planter dealers, offer planter unit testing with the use of several planter test stands on the market. One of the more popular test stands being used is called the Meter Max, manufactured by Precision Planting (http://precisionplanting.com/). This type of planter test stand not only measures the accuracy of seeding rate, it can also give you an idea of the uniformity of the seed drop by virtue of the seed dropping onto a horizontal seed belt.

Check out the related references below for links to service support Web pages at Case-IH, Deere, and Kinze. Here are some general guidelines and tips for planter maintenance and adjustments.

- Clean the planter inside and out. This should have been done at the end of last year's planting season before the planter was "put to bed" for the off-season. Check for old seed left in the hoppers, mouse nests, and anything else that may interfere with the operation of the seed meter or seed drop tubes.

- Check and replace all worn out parts.
- Ensure that coulters and disc openers are aligned accurately.
- Replace worn seals and check trueness of fit of seed drum (Case IH Cyclo).
- Replace worn rubber seals on JD vacuum seed discs.
- Adjust or replace worn disc openers.
- For finger-pickup type planters, check finger-pickup back plates for rust buildup, seed treatment residues, and worn down 'dimples'. Check and adjust finger tension.
- Check condition of seed conveyor belt. Age + seed treatment = brittleness.
    - Also check condition of belt drive sprocket teeth.
- Replace worn chains. Lubricate or replace chain links.
- Inflate tires to their correct pressure.
- Clean seed tubes and monitor sensors to ensure accurate monitoring of seed flow.
- Replace seed tubes if excessively worn at bottom.

Calibrate the Planter

- For air or vacuum planters:
    - Calculate and record the seed weight for each seed lot you intend to plant.
    - Identify and record the correct pressure (air or vacuum) for the calculated seed weight.
    - Identify and record the correct seed disc (or drum) for the calculated seed weight.
- Double-check the operations manual and identify the correct transmission setting for the desired seeding rate.
- Calibrate actual seed drop against:
    - Planter transmission settings.
    - Planter monitor readouts.
- Calibrate at normal planting speeds and seeding rates.
    - Calibrate in as close to field conditions as possible.
    - Don't calibrate the planter in the farm lane.
- Calibrate pesticide and fertilizer planter attachments at same time because application rates can easily change from year to year.
- Check that the planter toolbar is parallel to ground when planter is in use because this affects disc opener depth, press wheel efficiency, and seed to soil contact.

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Table 1. Location information.

Year	Location	Area (acres)	Plot Length (feet)	Previous Crop	Tillage	Planted	Harvested
2004	PPAC	17	500	Soybean	Full width	21-May	27-Oct
2005	DPAC	29	1200	Soybean	Full width	9-May	10-Oct
2005	NEPAC	28	1400	Soybean	No-till	5-May	5-Oct
2005	PPAC	20	550	Soybean	Full width	18-May	18-Oct
2005	SEPAC	27	1400	Doublecrop soy	No-till	2-May	30-Sep
2005	TPAC	25	1100	Soybean	Full width	19-Apr	11-Oct
2006	DPAC	30	1200	Soybean	Full width	31-May	
2006	NEPAC	17	350	Soybean	No-till	8-May	*Abandoned*
2006	PPAC	21	535	Soybean	Full width	28-Apr	
2006	SEPAC	29	1300	Soybean	No-till	22-May	6-Oct

Table 2. Actual (measured) SD of plant spacing (inches) for the five targeted (treatment) plant spacing variability (TPSV) levels for the five locations of the 2005 study. Actual SD values represent means over two hybrids and the respective number of replicates for each location.

	Actual SD of plant spacing (inches)									
TPSV	DPAC		NEPAC		PPAC		SEPAC		TPAC	
0	2.4	e	2.3	e	1.8	e	2.5	e	2.7	e
2	3.1	d	3.0	d	2.6	d	3.2	d	3.2	d
4	4.7	d	4.6	c	4.3	c	5.0	c	4.6	c
6	6.3	b	6.2	b	5.8	b	6.2	b	6.3	b
8	8.1	a	8.1	a	7.8	a	8.0	a	7.7	a
LSD	0.2		0.3		0.3		0.4		0.5	

The LSD ($P \leq 0.10$) value can be used to compare any pair of Actual SD means within a location. Any pair of means within a column followed by different letters can be considered truly different and not an artifact of random chance or experimental error.

Table 3. Grain yield (bu/A) for the five targeted (treatment) plant spacing variability (TPSV) levels for individual site-years. Grain yield values represent means over two hybrids (one hybrid in 2004) and the respective number of replicates for each location.

TPSV	PPAC 04		DPAC 05		NEPAC 05		PPAC 05		SEPAC 05		TPAC 05		SEPAC 06	
0	192.4	a	190.8	a	193.8	a	139.0	ab	205.7	b	182.1	ab	193.0	a
2	191.8	a	186.6	b	190.2	ab	140.4	a	213.2	a	185.1	a	189.0	ab
4	185.2	b	184.7	bc	187.4	b	136.7	bc	204.6	b	183.1	a	182.2	c
6	183.6	b	184.3	c	187.5	b	136.6	bc	203.5	b	178.0	bc	185.0	bc
8	178.5	c	180.4	d	180.4	c	135.2	c	201.4	b	174.6	c	182.1	c
LSD*	1.7		2.1		4.0		3.0		6.2		4.2		5.7	

* The LSD ($P \leq 0.10$) value can be used to compare any pair of grain yield means within a location. Any pair of means within a column followed by different letters can be considered truly different and not an artifact of random chance or experimental error.

Table 4. Significance levels, slopes, and R squares of linear regressions of grain yield on actual PSV for individual site-years. Regressions were performed on treatment means.

Year	Location	Sig. F [1]	Slope [2]	R sq. [3]
2004	PPAC	< 0.01	-2.2	0.97
2005	DPAC	0.02	-1.5	0.87
2005	NEPAC	0.02	-2.0	0.90
2005	PPAC [4]	0.04	-0.8	0.80
2005	SEPAC [5]	ns		
2005	TPAC	0.04	-1.8	0.81
2006	SEPAC	0.07	-1.7	0.73

[1] *Sig. F = Significance level of the F value for the linear regression model. The term "ns" indicates probability levels greater than 0.10 considered to be statistically non-significant.*
[2] *Slope = Value of the linear regression "b" coefficient; equal to the change in yield (bu/A) per unit change in PSV (inches std. dev.).*
[3] *R sq. = The R square value or coefficient of determination that determines what fraction of the variation in grain yield is explained by the linear regression model. A value of 1.00 would equal 100%.*
[4] *The 2005 PPAC site experienced moderate to severe drought stress.*
[5] *The 2005 SEPAC site also experienced severe drought stress, but in spatially uneven patterns that forced me to try to identify spatially uniform areas within the field from which to extract yield data.*

Fig. 1. Frequency distribution of plant spacing variability (SD) among 354 surveyed commercial fields in Indiana and Ohio, 1987-1996.