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2005 Research Update:
Effect of Plant Spacing Variability on Corn Grain Yield

R.L. (Bob) Nielsen
Agronomy Department
Purdue Univ., West Lafayette, IN
Email: rnielsen@purdue.edu

Research Summary
The results of large-scale field research conducted in 2005 at five locations throughout Indiana indicate that uneven plant spacing within rows decreased corn grain yield at rates up to 2 bushels per acre for every inch increase in standard deviation of plant-to-plant spacing within a range of plant spacing variability from ~ 2 to ~ 8 inches.

Introduction
Stand establishment uniformity in corn is an intuitively important component for achieving the maximum yield potential in a given field in a given year. 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.

This report summarizes on-going large-scale field research on the effects of plant spacing variability (PSV) on the grain yield of corn. Background information on PSV, including earlier research on the topic, was provided in my 2004 research update (Nielsen, 2004).

Research Objectives
The objective of the 2005 field trials was to determine whether plant spacing variability influenced corn grain yield of two hybrids that differed for ear size determination characteristics, planted to a single aggressive seeding rate in large-scale field plots.

Research Procedures
Prior to the 2004 preliminary trial, 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 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 standard deviations (SD) of 0-, 2-, 4-, 6-, and 8-inches at a seeding rate of 34,848 seeds per acre (spa) with each PSV treatment composed of equal mixtures of gaps and crowded spaces. More background information on the testing of the seed discs and the resulting plant-to-plant spacing patterns was provided in my 2004 research update (Nielsen, 2004).

Two Bt-rootworm hybrids of similar relative maturity, but differing for ear size determination characteristics (fixed versus flex), were selected for the 2005 trials (Table 1). 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 five outlying Purdue research facilities: 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 eastcentral Indiana near Farmland, Southeast Purdue Ag. Center (SEPAC) in southeast Indiana near N. Vernon, and Throckmorton-Purdue Ag. Center (TPAC) in westcentral Indiana near Lafayette. Field sizes, previous crop, and tillage practices for the five locations are listed in Table 2.

At each location, the two hybrids and five PSV treatments were replicated in a splitplot 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 (550 to 1400 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 five trials were planted from mid-April through mid-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 2). 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 2) 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 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.

The trial at SEPAC (southeast Indiana) experienced severe drought stress mid-season that severely reduced plant growth and development on the sloping transition areas between the high ground and gullies in the field that ran across all three replicates. Additionally, the first replicate included nearly an acre of glyphosate-resistant marestail (aka horseweed, *Conyza canadensis*) and smaller areas of severe feeding damage from raccoon (mid-season), birds (late), and deer (late). Consequently, yield data were extracted from an area of visually uniform yields ranging from 230 to 500 feet long in the central portions of Reps 2 and 3 for data analysis.

Analyses of variance of the dataset 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 quantify the relationship between PSV and yield.

Results of the Trial

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 (Table 3). 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 five locations averaged about 94% (32,887 plants per acre) of the targeted seeding rate and were statistically similar among the five targeted PSV treatments (Table 4). Except for Pinney, correlations between actual PSV and plant population on a per plot basis were non-significant (Table 4). 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 four of the five locations but below average at PPAC (northwest Indiana) where serious moisture deficits existed throughout the growing season (Table 5). While yields at the other four 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 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 five locations, with the greatest yields generally occurring with the more uniformly spaced treatments and lowest yields occurring with the least uniformly spaced treatments (Table 5). The exception was at SEPAC where the 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 four of the five locations in this trial (Table 6). While significant, the observed rates of yield loss per inch of SD (0.78 to 1.99 bushels per acre [bpa]) were less than the average loss rate measured in the 2004 preliminary trial (2.2 bpa), 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 five locations (Table 5). 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 (Table 7). Grain yield of the fixed-ear hybrid at DPAC decreased at a greater rate in response to uneven plant spacing than did the flex-ear hybrid. The opposite occurred at the PPAC location where the fixed-ear hybrid did not respond at all to uneven spacing. At TPAC, neither hybrid responded linearly to increasing levels of PSV.

Conclusions

Results from a preliminary field-scale trial in 2004 (Nielsen, 2004) and this first year of an expanded field trial in 2005 support those observed more than 15 years ago over 8 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 trial to represent opposite ear size determination characteristics did not differ consistently in their response to uneven plant spacing.

Plans for Future Research

My intent for 2006 is to continue this large-scale field trial at the same five outlying Purdue research centers (northwest, northeast, eastcentral, westcentral, and southeast) using the same two hybrids.

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- PPAC: Jon Leuck, superintendent; Justin Grimble; and Mark O'Neal.
- SEPAC: Don Biehle, superintendent; Bill Maschino, and Dan Bauerle.
- TPAC: Jay Young, superintendent; Nate Linder, Pete Illingworth, and Josh Synesael.

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Related References

Doerge, Tom, Tom Hall, and Doug Gardner. 2002. **New Research Confirms Benefits of Improved Plant Spacing in Corn.** Crop Insights Vol. 12, No. 2. Pioneer Hi-Bred Int'l, Johnston, IA. Available online at https://www.pioneer.com/growingpoint/agronomy/crop_insight/plantspacing.jsp. [URL verified 1/2/06, but access requires free registration to Pioneer Growing Point™ Web site].

Liu, Wiedong, Matthijs Tollenaar, Greg Stewart, and William Deen. 2004. **Impact of Planter Type, Planting Speed, and Tillage on Stand Uniformity and Yield of Corn.** Agron. J. 96:1668-1672.

Nielsen, R.L. (Bob). 1991 (Rev. 2001). **Stand Establishment Variability in Corn.** Purdue Univ. Agronomy Dept. publication AGRY-91-01. Available online at http://www.agry.purdue.edu/ext/pubs/AGRY-91-01_v5.pdf. [URL verified 12/22/05].

Nielsen, R.L. (Bob). 2004. **Effect of Plant Spacing Variability on Corn Grain Yield.** Purdue Univ. Agronomy Dept.. Available online at http://www.kingcorn.org/research/psv/Update2004.pdf [URL verified 12/22/05].

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Table 1. Hybrid information.

Diener brand	1076RW	1065RW
Rel. maturity	107	106
Seed lot	G401DRI	R515DRA
Origin	Chile	Illinois
Grade	R	R
Bag weight	64.5	57.5
Kernels/bag	80000	80000
Seeds/lb	1240	1391
Insecticide	Poncho 250	Poncho 250
Fungicide	Maxim XL	Maxim XL
Ear flex rating	Fixed	Flex
Warm Germ.	95%	95%
Germ. date	Dec-04	Dec-04

Table 2. Location information.

Location	Acreage	Plot lgth	Previous crop	Tillage	Planted	Harvested
	Acres	*Feet*				
DPAC	29	1200	Soybean	Full width	9-May	10-Oct
NEPAC	28	1400	Soybean	No-till	5-May	5-Oct
PPAC	20	550	Soybean	Full width	18-May	18-Oct
SEPAC	27	1400	Doublecrop soy	No-till	2-May	30-Sep
TPAC	25	1100	Soybean	Full width	19-Apr	11-Oct

Table 3. 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 4. Final plant populations (plants per acre) associated with the five targeted (treatment) PSV levels (TPSV) for the five locations of the 2005 study. Plant population values represent means over two hybrids and the respective number of replicates for each location.

	Plant population (plants/acre)				
TPSV	DPAC	NEPAC	PPAC	SEPAC	TPAC
0	32757	33164	34081	32845	32409
2	32148	33338	33803	32496	31973
4	32191	33512	34012	32583	32496
6	32104	32757	33663	33280	32583
8	32452	33106	33245	32409	32757
Mean	32330	33175	33761	32723	32444
Correlation*	-	-	-0.34	-	-
Corr. Prob.**	ns	ns	0.02	ns	ns

** Values represent Pearson Correlation Coefficients calculated on a per plot basis between actual PSV and plant population at each location.*

*** Correlation Probability > |r| under H0: Rho=0. The term "ns" indicates probability levels greater than 0.10 considered as non-significant.*

Table 5. Grain yield (bu/ac) for the five targeted (treatment) plant spacing variability (TPSV) levels for the five locations of the 2005 study. Grain yield values represent means over two hybrids and the respective number of replicates for each location.

	Grain yield (bu/ac)									
TPSV	DPAC		NEPAC		PPAC		SEPAC		TPAC	
0	190.8	a	193.8	a	139.0	ab	205.7	b	182.1	ab
2	186.6	b	190.2	ab	140.4	a	213.2	a	185.1	a
4	184.7	bc	187.4	b	136.7	bc	204.6	b	183.1	a
6	184.3	c	187.5	b	136.6	bc	203.5	b	178.0	bc
8	180.4	d	180.4	c	135.2	c	201.4	b	174.6	c
LSD*	2.1		4.0		3.0		6.2		4.2	
*Hybrid x TPSV***	*0.04*		*ns*		*0.02*		*ns*		*0.03*	

** The LSD (P ≤ 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.*

*** Hybrid x TPSV = Significance level of the F value for the interaction between Hybrid and TPSV treatments. The term "ns" indicates probability levels greater than 0.10 considered as non-significant.*

Table 6. Significance levels, slopes, and R squares of linear regression of grain yield on actual PSV for the five locations of the 2005 study. Regressions performed on treatment means.

	DPAC	NEPAC	PPAC	SEPAC	TPAC
Sig. F*	0.02	0.02	0.04	ns	0.04
Slope**	-1.52	-1.99	-0.78	-	-1.81
R sq. ***	0.87	0.90	0.80	-	0.81

** Sig. F = Significance level of the F value for the linear regression model. The term "ns" indicates probability levels greater than 0.10 considered as non-significant.*

*** Slope = Value of the linear regression "b" coefficient; equal to the change in yield (bu/ac) per unit change in PSV (inches std. dev.).*

**** 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%.*

Table 7. Grain yield response to the five targeted (treatment) plant spacing variability (TPSV) levels for each of two hybrids at three locations with significant Hybrid × TPSV interactions.

	DPAC				PPAC				TPAC			
TPSV	1065RW (Flex)		1076RW (Fixed)		1065RW (Flex)		1076RW (Fixed)		1065RW (Flex)		1076RW (Fixed)	
0	199.3	a	182.4	a	142.4	a	135.5	a	191.9	a	172.2	b
2	196.6	ab	176.7	b	140.9	a	139.9	a	189.3	ab	180.9	a
4	193.9	bc	174.8	b	134.2	b	139.3	a	194.5	a	171.8	b
6	193.7	bc	175.7	b	135.0	b	138.2	a	183.1	b	173.0	b
8	192.8	c	168.1	c	135.0	b	135.5	a	183.2	b	166.0	c
LSD*	3.5		2.8		4.3		ns		6.8		5.5	
Sig. F**	0.04		0.05		0.08		ns		ns		ns	
Slope***	-1.05		-1.92		-1.29		-		-		-	
R sq.****	0.81		0.78		0.69		-		-		-	

** The LSD ($P \leq 0.10$) value can be used to compare any pair of grain yield means within a specific location-hybrid column. 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.*

*** Sig. F = Significance level of the F value for the linear regression model. The term "ns" indicates probability levels greater than 0.10 considered as non-significant.*

**** Slope = Value of the linear regression "b" coefficient; equal to the change in yield (bu/ac) per unit change in PSV (inches std. dev.).*

***** 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%.*