THE EFFECT OF WITHIN-ROW SPACING VARIABILITY ON GRAIN YIELD OF CORN, *ZEA MAYS* L.

by

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B. S., South Dakota State University, 1971

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

Approved by:

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INTRODUCTION

Corn, *Zea mays* L., has been an increasingly important factor in man's existence since its discovery. Breeding techniques, both intentional and unintentional, have given the world this domesticated plant which responds well to management techniques but can't survive in the wild. Productivity of corn in the United States has risen dramatically since the turn of the century. Development of hybrid seed, massive use of fertilizers, modernization of mechanical equipment, and the extensive use of modern pesticides have all contributed to this increase.

With these innovations came changes in cultural practices. Plant populations increased and row spacing decreased. Scientific research guided the farmer through this period by showing him which methods would produce more corn on a specified area of land. However, few have studied the effect of plant spacing variability within the row.

The objective of this research was to determine the effect of variability of spacing within the row on corn yields of plot-size areas and individual plants. An attempt was made to discover whether this effect, if measurable, was similar under dryland and irrigated conditions. Maturity differences between hybrids were studied to observe any inconsistency in yield response to spacing variability. The possibility that soil type might influence corn's response to reduced standard deviation of spacing led to the placement of a study on two different soil types at nearby sites.

REVIEW OF LITERATURE

In the past one hundred years, considerable effort and ingenuity have gone into planting techniques aimed at corn yield increases. Research has been conducted over this period to determine the best planting methods for farm use. Many of the early studies showed no yield changes by going from several kernels per hill to drilled corn (1,14,18,26). Dungan (7) attributed this to the requirement for weed control by cross cultivation and its restriction on row spacing. Yield levels were lower then than now because an increase in population required an increase in seeds per hill and weaker plants resulted from this extreme competition.

Kiesselbach et al. (14) obtained a 3 percent yield increase in drilled corn over checked corn in an 11 year study. This difference was not statistically significant and the authors concluded that the checked corn offered the advantage of being cross cultivated. Morrow and Hunt (18) in an 1891 publication saw no difference in drilled versus hilled corn. In 1912 Roberts and Kinney (21) reported a modest 4.7 percent yield increase attributable to drilled corn when compared to the more traditionally hilled corn. Stringfield and Thatcher (26) claimed no consistency in yield advantage for either hilled or drilled corn at any single population.

Later work indicated yield potential at the same population was higher when planted as nearly equidistant as possible. The advent of chemical pesticides, acceptance of hybrid corn, and increased use of fertilizers raised the yield potential dramatically (15). In experimenting with different production pracitices (hill vs. drill and row width variation), many researchers conducted studies in which it is difficult or impossible to separate the effect of the planting method from the row width influence

(2,3,5,13,20,23).

Collins and Shedd (3) noted a yield increase of from 4.6 to 9.2 percent for single plant 53.3 by 53.3 cm spacing over a 4-plant 106.7 by 106.7 cm spacing. Their study also included single plant 106.7 by 26.7 cm spacing which showed no advantage over the 106.7 by 106.7 cm 4-plant arrangement. The authors implied that one less cultivation would be required for 53.3 or 76.2 cm rows than was necessary for the 106.7 cm row spacing.

Pfister (20) obtained a 39.9 percent increase from corn drilled in 50.8 or 55.9 cm rows over corn checked in 101.6 cm rows. A somewhat higher plant population in the drilled corn may have accounted for a portion of this increase, but the author attributed it to row spacing without investigating the effect of the distance between plants within the row. Hoff and Mederski (13) reported a 7 percent yield increase for corn grown in equidistant spacing over that in 106.7 cm row spacing. In this study on phosphorus uptake, they noticed that the phosphorus content of the fodder of equidistantly spaced plants was always higher than that of plants grown in 106.7 cm rows. The authors claimed that, "Equidistant planting apparently reduced competition between plants for soil phosphorus or, in some other way, enabled the individual plants to absorb more phosphorus."

In a weed control study, Colville and Burnside (5) found that hand weeded corn grown on 50.8 cm squares outyielded that grown on 101.6 cm squares at the same population by 39 percent. Even greater increases were seen on plots that received herbicide applications--94 percent for atrazine and 55 percent for 2,4-D.

Shubeck and Young (23) assumed that equidistant plant spacing results in optimal use of light, nutrients, and water. Equidistant planting of corn in a diamond shape with 46.7 cm rows and corn grown on 50.8 cm squares resulted in yield increases of 7.9 percent and 7.0 percent, respectively, over corn drilled in 106.7 cm rows. Bunting (2) confounded row spacing and plant spacing within the row in his study on dry matter production of corn. The author noticed a trend toward increased yield with increased uniformity of planting. He claimed that yield increases could not be expected to exceed 5 percent with more even spacing and concluded that the observed trend was not significant.

Many other researchers studied the effect of spacing within the row while maintaining a uniform row spacing. Dungan (7) reported a 12.6 percent advantage in grain yield from single plant hills when compared to multiple plant hills at optimum plant population. A larger percentage of single plants produced tillers than was noted for multiple plant hills indicating that single plants were able to more efficiently utilize the total land area. He attributed the increase in grain yield of single plants over multiple plant hills to larger ears and more ears per plant.

Kohnke and Miles (15) showed that yields of corn drilled in 106.7 cm rows surpassed those of hilled corn by 8.9 percent when planted at optimum population. Rounds et al. (22) found a 7.0 percent average yield advantage for drilled versus hilled corn. The authors' only justification for hilling corn was cross cultivation. Colville and McGill (6) reported that drilled corn consistently produced more grain than hill dropped and checked corn at the same plant populations. In this study over 4 years and 3 locations, they claimed an average increase of 12.4 percent for drilled corn. Colville (4) stated that the major contributor to this yield increase was a 14.1 percent increase in ears per 100 plants. Average yields during three years of this study showed that drilled corn reached its maximum yield at a plant population of 59,280 plants per hectare, whereas checked corn reached its maximum at 49,400 plants per hectare.

Fayemi (11) reported yield increases from 6 percent to 23 percent for drilled corn over checked corn at the same row spacing and plant population. He also concluded that drilled corn has a higher optimum plant population than checked corn under conditions in Nigeria. Stanisavljevic (25), however, obtained higher yields with 2 plants per hill than 1 plant per hill at the same plant population. Woolley et al. (27) found no yield advantage for corn grown in hills of 1, 2 or 4 plants at the same population and row spacing.

Successive studies were conducted by Esechie and Krall on the effect of within-row variability on grain yield of corn. Esechie (10) found no relationship between grain yield and a measure of intra-row variability--standard deviation of spacing. Krall (16) found a significant relationship between yield and standard deviation of spacing in four of six experiments. His results showed that standard deviation accounted for from 5.9 to 16.1 percent of the yield variability in the four experiments where a significant relationship existed. He suggested that soil type could influence this relationship.

Some research has been done studying the effect of spacing within the row on individual plants. Haynes and Sayre (12) studied the effect of increased population on the rooting pattern of individual plants. They concluded that rooting patterns changed from circular to oblong with increased intra-row competition and that this increased crowding caused roots to extend further from the parent plant than would be the case if no competition existed. Erbach et al. (9) conducted experiments studying the effect of proximity to adjacent plants within the row on individual plant grain yields. They stated *a priori* that, "Improving plant spacing uniformity by decreasing the intra-row spacing variance should be as effective in increasing yields as improving spacing uniformity by decreasing row width." Their results showed that plant population, not plant spacing uniformity, was the more important parameter affecting plant yield, and they concluded that improving intra-row spacing may not significantly increase total yield on a field basis.

Dungan et al. (8) described some unpublished research in which the effect of missing plants in a hill was measured. In a 3 plant per hill population, 43 percent of the grain loss of a missing hill was recovered by the 4 nearest hills. When 2 plants were missing from this hill, 68 percent was recovered by the remaining plant and the 4 nearest hills. Removal of 1 plant in a hill resulted in 89 percent recovery by neighboring plants. The authors stated that, "Under the conditions of these tests, it appeared that corn plants adjoining a gap or reduced population were able to go a considerable way in compensating for the stand deficiency yet they were never able to fully replace the loss in grain yield."

Some studies have been conducted on the regularity of seed drop by planting machinery. Mattioli and Capilouto (17) tested 15 planting machines for regularity of seed spacing within the row. Their criterion for evaluating uniformity was the standard deviation of spacing from a mean of 22 cm. In a minimum speed test (7 km/hr) the value of the standard deviation ranged from 15.4 cm to 38.7 cm for the machines tested. Using the same criterion in studying emerged plants in the field, Krall (16) found a range of values from 6.6 cm to 18.4 cm on a total of 227 plots in 37 farmers' fields.

MATERIALS AND METHODS

Hand- and machine-planting were used to determine the effects of within-row spacing variability on corn grain yield. Four hybrids of differing relative maturities (Table 1) were planted at three locations in eastern Kansas: the Kansas River Valley Experiment Field at Silver Lake, the Ashland Agronomy Farm, and the Manhattan Agronomy Farm. One of the four was also planted at each of two other locations, the Kansas River Valley Experiment Field at Rossville and the Cornbelt Experiment Field at Powhattan. Silver Lake, Rossville, and Ashland were irrigated; the other two locations were not. Plots were furrow-irrigated at Silver Lake, Ashland, and one of two sites at Rossville. A loamy fine sand site at Rossville, located about 0.5 km from the furrow-irrigated silt loam site, was sprinkler-irrigated. All locations were managed to insure maximum yields under existing climatic conditions.

Individual seeds were hand-planted in 76.2 cm rows to desired final populations. To attain higher variability of spacing, plots were machine-planted at a higher population than desired and emergence losses allowed to thin the population (Table 2). Subplots 3.05 meters long containing identical numbers of plants in both hand- and machine-planted plots were selected and marked. Low variability of spacing was achieved by choosing subplots from uniform, hand-planted stands. Some subplots with barren segments were chosen in the machine-planted areas for high variability of spacing. The hand- and machine-planted plots of each hybrid were located adjacent to each other and were considered as identical treatments. A minimum of 50 subplots per hybrid at each location was considered necessary for regression analysis (Table 3).

Table 1. Hybrids used in this study.

Hybrid	Grain Color	Relative Maturity
Funks G-4444	Yellow	Early
BoJac X-56*	Yellow	Medium
Pioneer 3195+	Yellow	Medium-late
DeKalb XL 390	White	Late

*Only hybrid planted at Powhattan +Only hybrid planted at Rossville

Table 2. Date of planting, seeds planted, desired population and plants per subplot for each location.

Location	Date of Planting	Seeds planted/Ha		Desired Population Plants/Ha	Plants Subplot
		Hand	Machine		
Silver Lake	April 12	51,645	65,373	51,645	12
Rossville	April 13	51,645	65,373	51,645	12
Ashland	April 26	51,645	65,373	51,645	12
Manhattan	May 14	43,037	51,645	43,037	10
Powhattan	May 11	38,734	46,527	38,734	9

Table 3. Replications, plot areas, and number of subplots for each location.

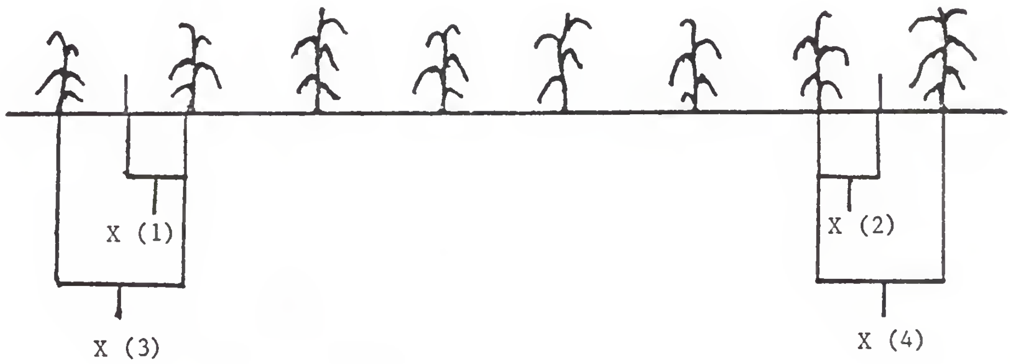
Location	Replications	Plot area (Rows X Length in meters)		Number of Subplots		
		Hand	Machine	Hand	Machine	Total
Silver Lake	2	6 X 50	6 X 50	107	171	278
Rossville	2	8 X 50	24 X 50	35	108	143
Ashland	4	4 X 50	4 X 50	60	176	236
Manhattan	2	4 X 30	6 X 30	107	137	244
Powhattan	1	8 X 50	24 X 50	14	84	98

Distances between all plants within each subplot as well as the distance to the next adjacent plant outside each end of the subplot were measured and recorded. Using the individual spacing measurements, the standard deviation of spacing was calculated for a measure of within-row variability for each subplot (24). Referring to Figure 1, slight variations in area harvested were accounted for by the following formula:

$$\text{Area harvested } (m^2) = .762 \times (3.05 - X(1) - X(2) + X(3)/2 + X(4)/2)$$

X(1) and X(2) are distances from the last plant within the subplot to the end of the 3.05 meter section. X(3) and X(4) are distances from the last plant within each end of the subplot to the next adjacent plant outside the subplot.

Figure 1. Subplots and measurements used in calculation of actual area harvested.

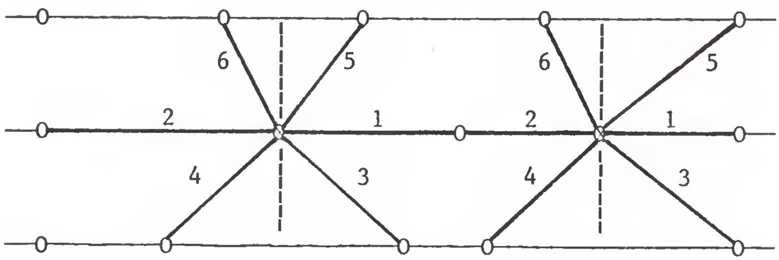


All subplots were harvested except those with plants broken below the ear or damaged by animals. Linear regressions of grain yield (kg/ha) and standard deviation of spacing (cm) were performed for subplot data on each hybrid and location.

Individual Plant Yields

The effect of intra- and inter-row spacing on individual plant grain yield was studied at three locations: Manhattan, Ashland, and Powhattan. All four hybrids were studied at Manhattan, while BoJac X-56 and Pioneer 3195 were examined at Powhattan and Ashland, respectively. Six measurements were made on alternate plants within a machine-planted row. These measurements consisted of the intra-row distance to the nearest plant in both directions and the inter-row distance to the nearest plants on each side of a perpendicular to both adjacent rows (Figure 2). Individual plants were harvested and ear number per plant was recorded. They were then dried and ear weight and grain weight (in grams) on a dry weight basis determined. Multiple regressions were performed between individual plant yields and various combinations of the six measurements in an attempt to determine the effect of intra-row as well as inter-row spacing on individual plant grain yield. Plants which were damaged or produced no grain were omitted from the regression analyses in order to remove misleading information.

Figure 2. Measurements taken for use in multiple regression analysis of individual plant yield.



RESULTS AND DISCUSSION

Grain yields from the subplots were related to the standard deviation of spacing by the linear regression equation Y = A + BX. Y represents the dependent variable, grain yield; A is the intercept of the regression line at zero standard deviation of spacing; B is the slope of the line; and X is the standard deviation of spacing in centimeters.

Yields were significantly related to standard deviation of spacing at all locations (Table 4, Figures 3 and 4). Slopes of these regression equations were negative and significantly different from zero for all locations over hybrids. From 2.3 to 15.0 percent of the yield variability can be attributed to the relationship between yield and standard deviation of spacing as shown by the value for the coefficient of determination--r^2 (Table 4). The two dryland locations, Manhattan and Powhattan, had the highest r^2 of the locations studied. Although inconclusive, this indicates that the negative relationship between yield and standard deviation of spacing was more stable for dryland than irrigated locations.

Table 4. Linear regression analyses of yield versus standard deviation of spacing at each location.

Location	A	S_A	B	S_B	r^2	Significance Level
Silver Lake	9,344	190	-47.51	17.58	.026	.004
Rossville	9,823	189	-31.73	17.51	.023	.036
Ashland	11,132	194	-40.52	17.45	.023	.011
Manhattan	7,997	152	-48.27	13.66	.049	<.001
Powhattan	3,806	254	-95.95	23.35	.150	<.001

Results of the regression analyses of hybrids over locations are not as consistent (Table 5, Figure 5). Only two of the four hybrids showed

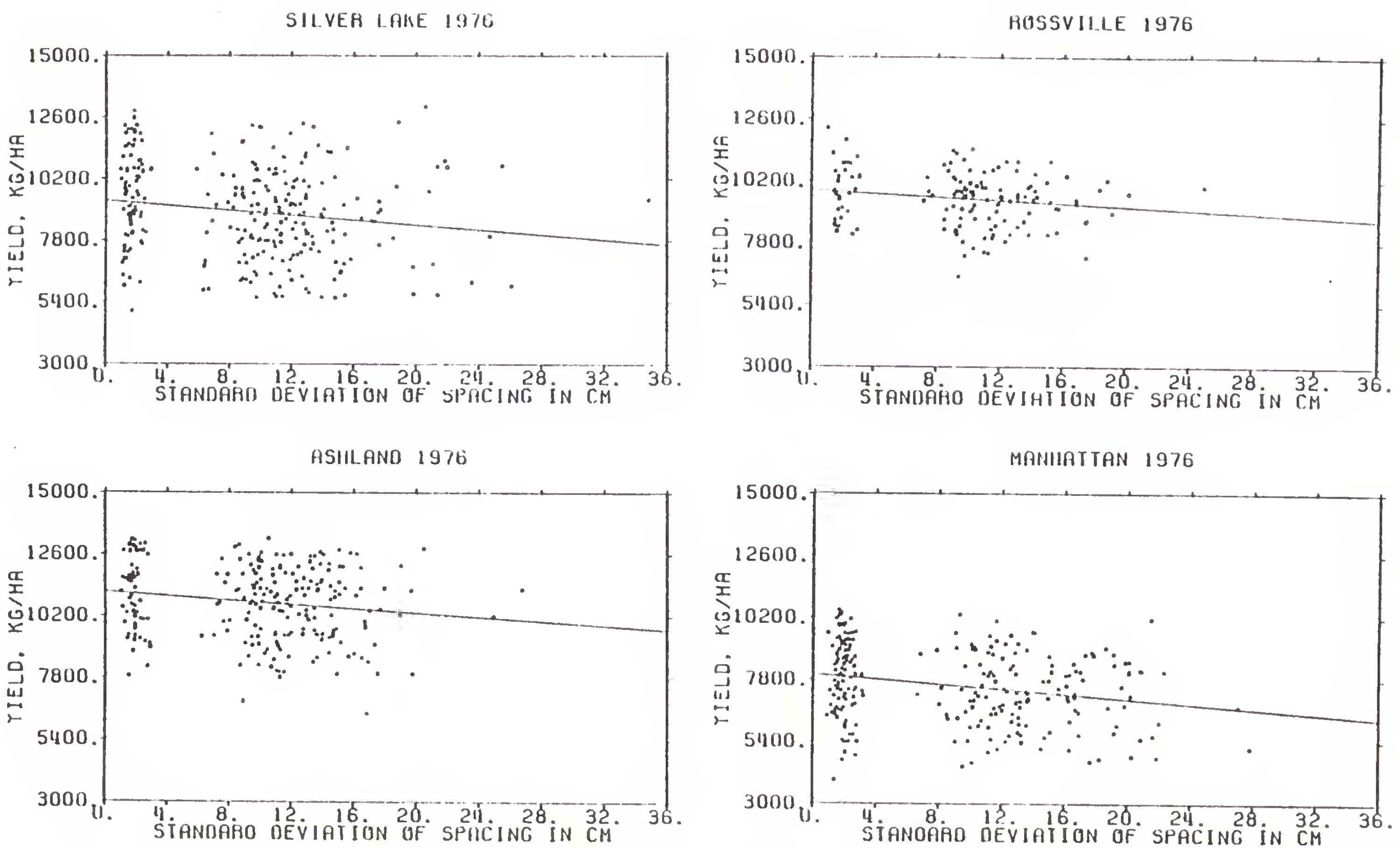


Figure 3. Regression lines and data points of all hybrids at each location.

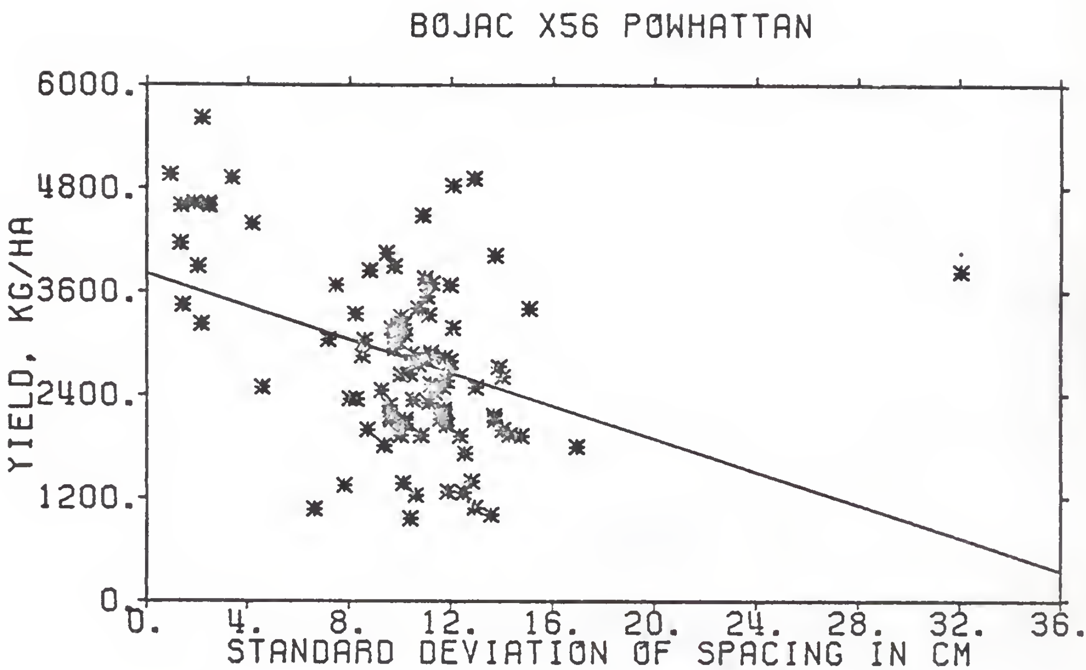


Figure 4. Regression line and data points of BoJac X-56 at Powhattan.

significant negative relationships between yield and standard deviation of spacing, and these only accounted for 0.9 and 3.8 percent of the yield variability. Both dryland and irrigated locations were included in these analyses possibly reducing the significance of the effect because the yield level of the dryland locations was lower.

The early hybrid, Funks G-4444, showed an insignificant positive slope. This hybrid probably should have been planted at a higher population in order to take advantage of its shorter stature, fewer leaves, and lower leaf area per plant. The population used resulted in little inter-plant competition. No relationship between yield and standard deviation of spacing was found for that hybrid.

Table 5. Linear regression analyses of yield versus standard deviation of spacing of each hybrid over locations.

Hybrid	A	S_A	B	S_B	r^2	Significance Level
Funks G-4444	7,780	177	6.28	17.95	.001	.364
BoJac X-56	9,175	356	-120.83	33.08	.038	<.001
*BoJac X-56	10,661	183	-47.20	17.03	.032	.003
Pioneer 3195	9,696	152	-23.10	13.78	.009	.047
DeKalb XL 390	8,483	380	-21.14	33.25	.002	.263

*Results from Powhattan were omitted from the analysis.

Results from two analyses are included for BoJac X-56. The Powhattan location yielded so poorly (with other problems to be discussed later) that a separate regression equation was run with the Powhattan results left out (Table 5). The reduction in slope is immediately evident, but this is offset by a reduction in the standard deviation of the estimate of the intercept (S_A) and slope (S_B). The representation of this last analysis is shown in Figure 5. The low yield level at Powhattan caused the slope to steepen in the original regression but nearly doubled S_A and S_B. A significant relationship was apparent in both analyses, however.

Pioneer 3195 also revealed a negative slope and significance although not so much as BoJac X-56. The lack of significance for DeKalb XL 390 is partially attributable to the small number of observations associated with a low standard deviation of spacing (Figure 5). A greater variability of yield among subplots was also apparent for this hybrid as seen by the values for S_A and S_B (Table 5). A discussion of the results from each location follows.

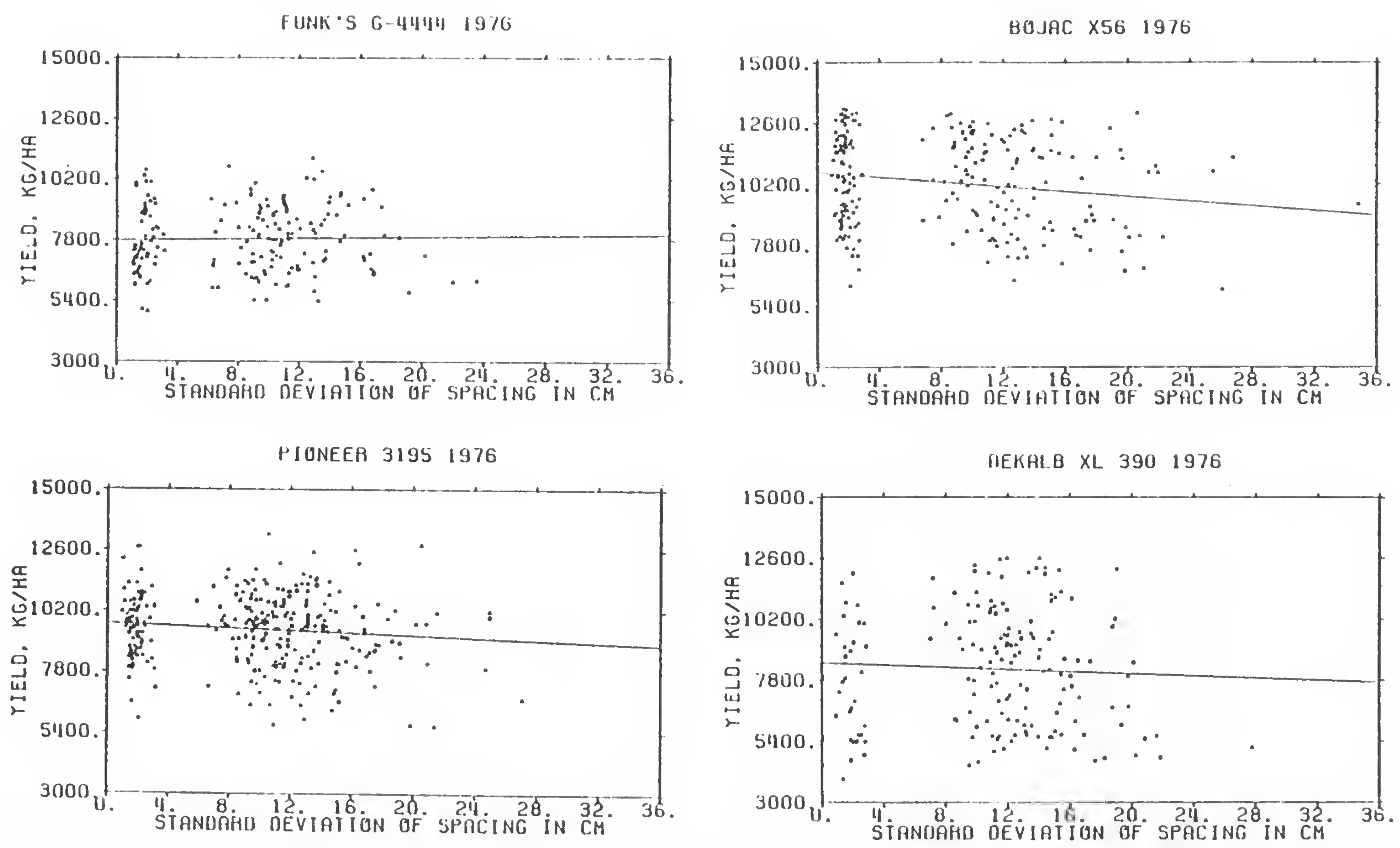


Figure 5. Regression lines of each hybrid over all locations. (Powhattan data omitted for BoJac X-56.)

Silver Lake

Results of the regression analyses as shown in Table 6 show a negative relationship between yield and standard deviation of spacing for three hybrids. The problem of plant population for Funks G-4444 was mentioned previously. Intra-row variability accounted for 4.7 and 17.3 percent of the yield variability for BoJac X-56 and Pioneer 3195, respectively. No such conclusion could be drawn for DeKalb XL 390 since no statistical significance was proven. The lack of significance for that hybrid can be attributed to the limited number of subplots in the low range of standard deviation (Figure 6). In regression analysis it is very important to have enough points at the extremes of the independent variable to reduce the variance of the slope and allow an accurate determination of that slope. This was not the case so a significant relationship was not found even though a trend is evident.

Table 6. Regression analyses of each hybrid at Silver Lake.

Hybrid	A	S_A	B	S_B	r^2	Significance Level
Funks G-4444	7,752	238	11.03	26.83	.002	.341
BoJac X-56	10,754	267	-47.84	23.29	.047	.022
Pioneer 3195	9,990	342	-103.39	30.77	.173	.001
DeKalb XL 390	8,899	562	-72.68	47.16	.042	.065

It might be pointed out that the results of the analysis for the Pioneer hybrid gave the highest r^2 of all the analyses at all locations. Yet nearly 83 percent of the yield variability was left unaccounted for. This means that water holding capacity, nutrient availability, available light, genetic variability, diseases, insects, or some unknown factor still must be responsible for the greatest amount of variability in grain yield.

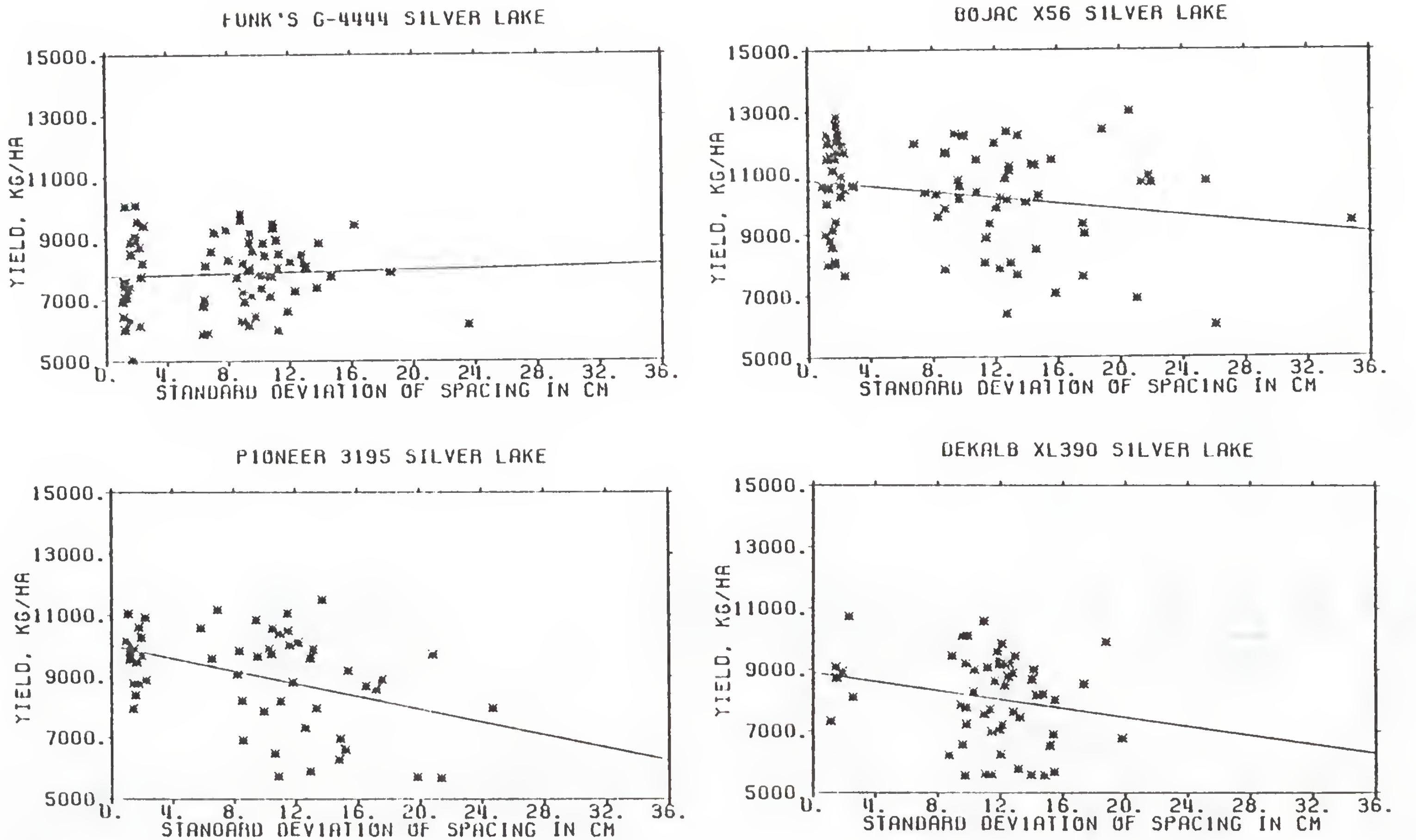


Figure 6. Regression lines for each hybrid at the Silver Lake location.

Rossville

The two sites at Rossville were chosen because of their proximity and dissimilarity of soil type. This tested the hypothesis that standard deviation of spacing is more critical on a sandy soil than a heavier textured soil. No statistical significance could be attributed to the effect of intra-row variability on yields for either the loamy fine sand or the silt loam. However, these analyses showed slopes and intercepts which were nearly equal and not statistically different from each other (Table 7, Figure 7). Combining these two sites, a significant relationship between yield and standard deviation was observed (Table 4, Figure 3) accounting for 2.3 percent of the yield variability.

Table 7. Regression analyses of yield from each soil type at Rossville.

Soil type	A	S_A	B	S_B	r^2	Significance Level
Loamy fine sand	9,893	286	-30.73	24.86	.021	.110
Silt loam	9,799	253	-38.10	25.22	.032	.068

As mentioned previously, Krall (16) hypothesized a possible interaction between soil type and yield response to standard deviation of spacing. This could not be verified at this location, even though the two soils were located only 0.5 km apart and managed in a like manner. The silt loam was not as finely textured as the soils with which Krall worked, but the proximity of two quite different soils should be a better test of soil type than soils in separate climates.

Ashland

BoJac X-56 was the only hybrid that showed a significant relationship between yield and standard deviation of spacing (Table 8, Figure 8). This

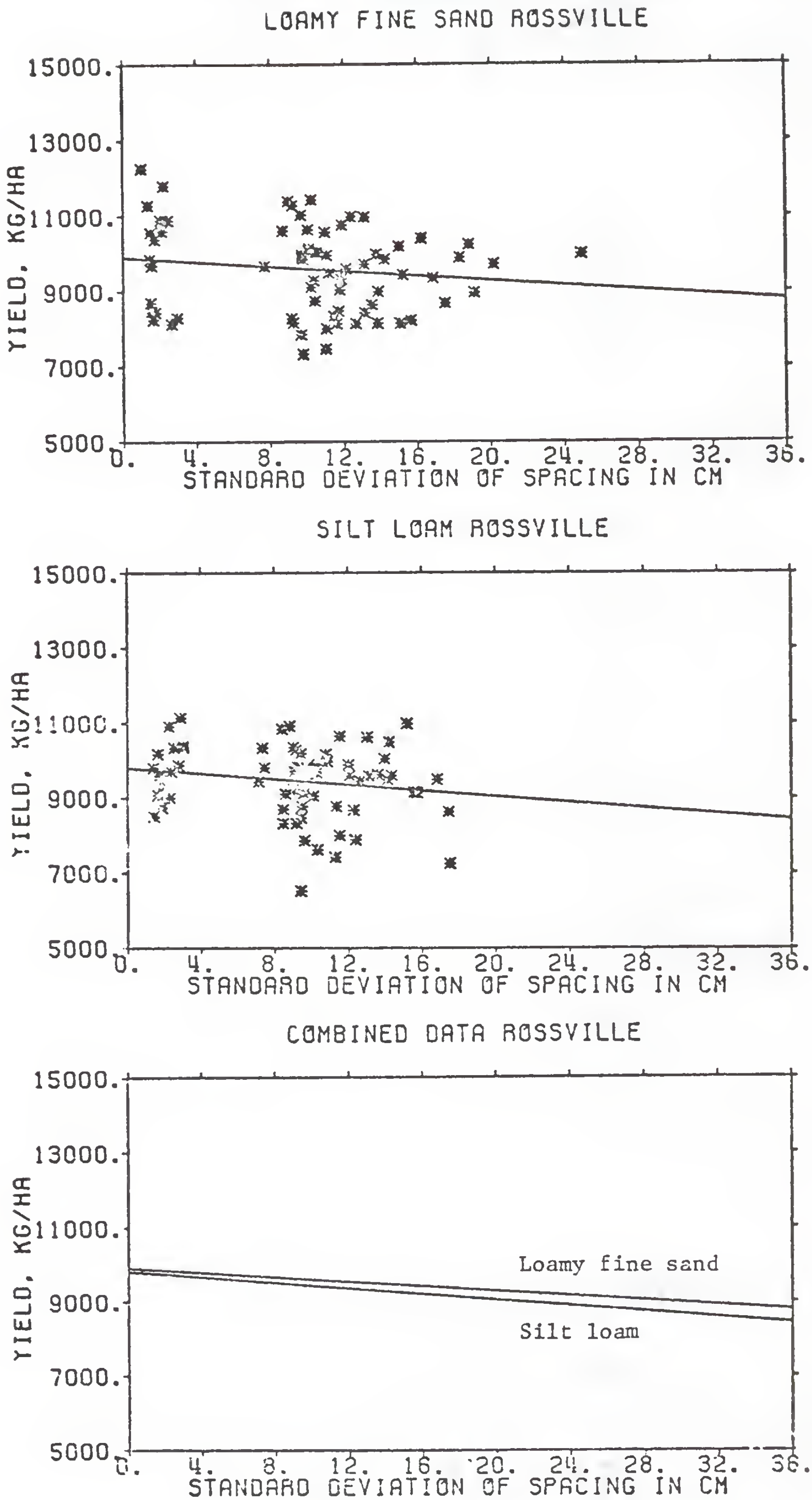


Figure 7. Regression lines at each soil site at Rossville.

measure of intra-row variability accounted for 5.4 percent of the yield variability. The other three hybrids had too few subplots with low standard deviation of spacing to accurately predict the slope of the regression line. All four hybrids produced their highest yields at Ashland. This could have been the result of a mistake in fertilizer calibration resulting in the application of 236 kg N/ha. This rate was twice that recommended for the plot area. A combination of irrigation and excess nitrogen may have affected a possible relationship between yield and standard deviation of spacing for the two hybrids, Pioneer 3195 and DeKalb XL 390. Funks G-4444 showed a negative slope in the regression analysis. This indicates a yield response to reduction in standard deviation of spacing even though the final population was lower than the optimum. This contradicts the results obtained at Silver Lake.

Table 8. Regression analyses of each hybrid at Ashland.

Hybrid	A	S_A	B	S_B	r^2	Significance Level
Funks G-4444	9,559	329	-47.57	29.44	.055	.057
BoJac X-56	12,232	150	-29.91	15.28	.054	.027
Pioneer 3195	10,498	298	19.08	25.75	.009	.231
DeKalb XL 390	10,500	453	11.51	37.81	.002	.381

Manhattan

Yield levels for all four hybrids were lower at this dryland site than at the aforementioned irrigated locations. In the linear regression analyses, however, negative slopes were obtained for all hybrids. This relationship between yield and standard deviation of spacing was highly significant for the two earliest maturing hybrids. In these instances, standard deviation of spacing represented 9.5 and 8.8 percent of the yield

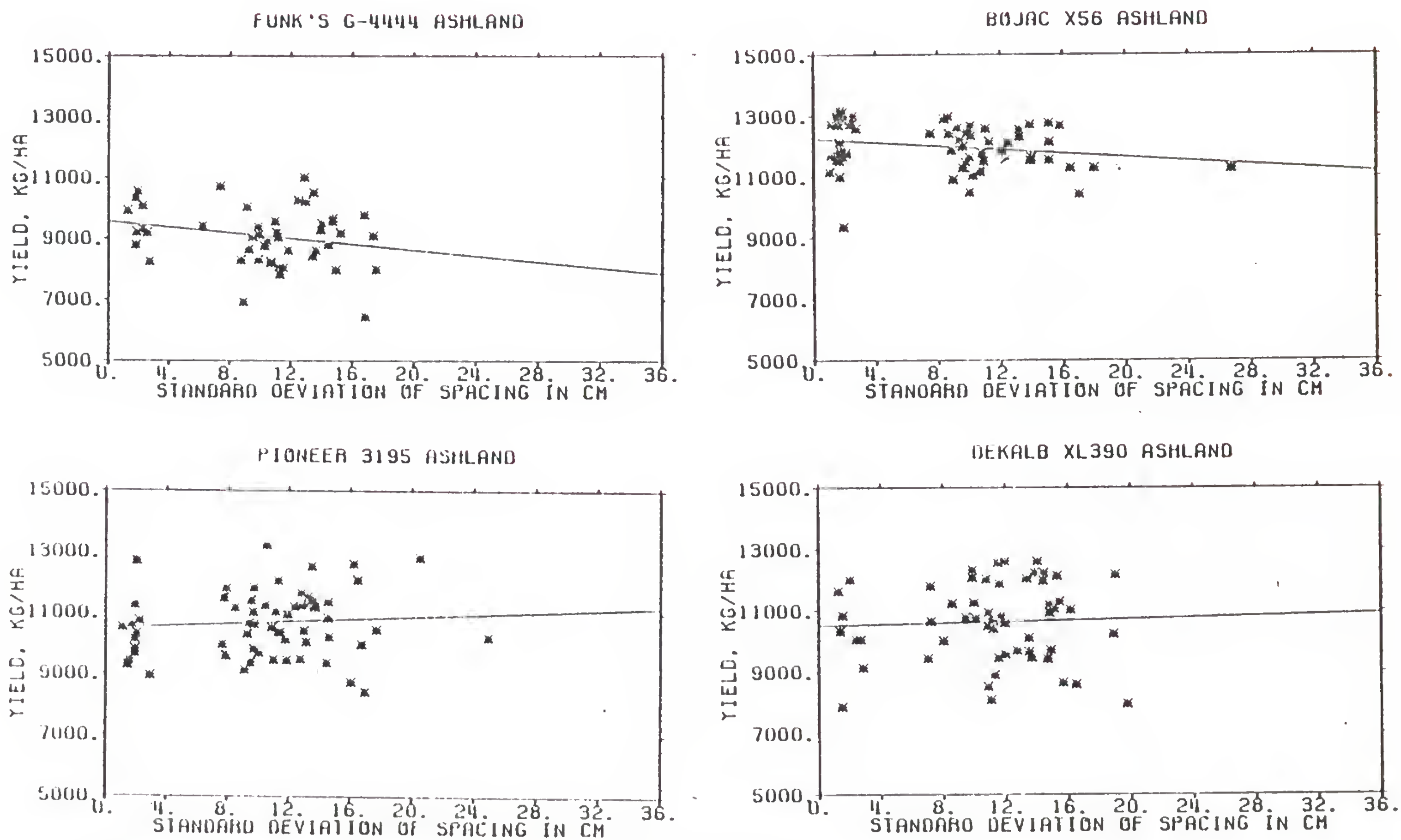


Figure 8. Regression lines of each hybrid at Ashland.

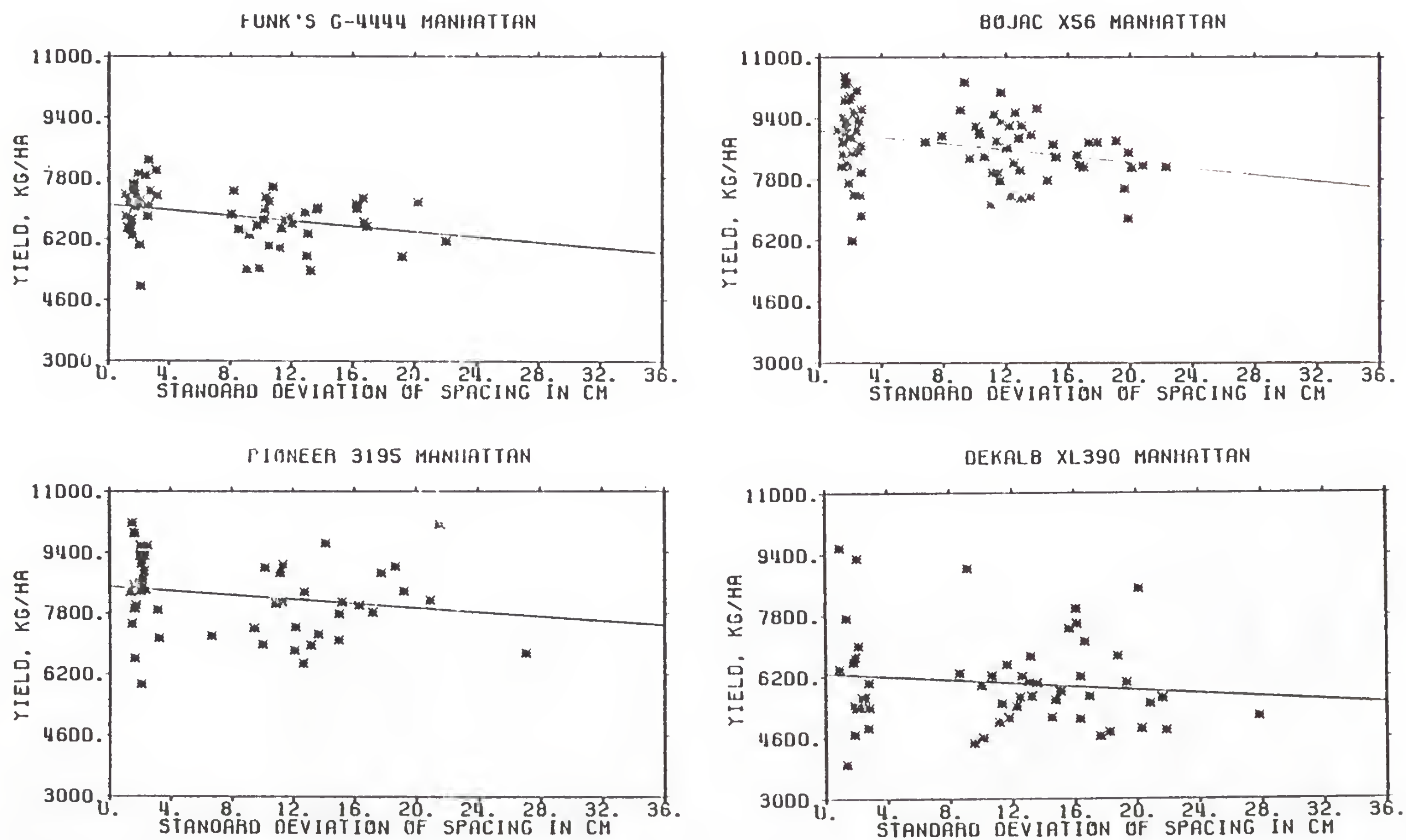


Figure 9. Regression lines of each hybrid at Manhattan.

variability. The hypothesis that variability of spacing within the row has less to do with final yield under dryland cropping practices seems to be invalidated by the responses shown in Table 9. These trends do not represent conclusive evidence of this, but they show the corn plant's apparent ability to respond to more uniform spacing with increased yields.

Table 9. Regression analyses of each hybrid at Manhattan.

Hybrid	A	S_A	B	S_B	r^2	Significance Level
Funks G-4444	7,098	143	-35.28	14.52	.095	.009
BoJac X-56	9,060	159	-41.22	14.96	.088	.004
Pioneer 3195	8,505	223	-28.17	20.37	.038	.087
DeKalb XL 390	6,275	308	-21.62	23.73	.015	.183

The large variability in yield for DeKalb XL 390 (Figure 9) may be a result of poor adaptation to dryland conditions. This white hybrid is generally grown in the fertile river valleys where available moisture is not limiting or irrigation is practiced. White hybrids generally are considered genetically inferior to yellow hybrids.

Powhattan

This dryland location gave the most significant results of any of the sites, with standard deviation of spacing accounting for 15 percent of the yield variability (Table 4). This is quite misleading, however, since analysis of variance showed a significant difference between the hand- and machine-planted plots. This was especially noticeable at harvest. The rows which were hand-planted had most of the ears well-filled with kernels, while the machine-planted rows had very few ears filled. This indicated a slight difference in the rate of development resulting in pollination problems for the machine-planted rows. For this reason, the results from Powhattan were left out when determining the relationship over all locations between yield and standard deviation of spacing for BoJac X-56 (Table 5, Figure 5). It is possible, but not likely that the regression analysis did reflect the true relationship for this location.

Individual Plant Yields

The premise of this small study was to pinpoint the contribution of precise planting to the grain yield of an individual plant. Referring to Figure 2, a description of the theory seems appropriate. It seemed logical to assume that the greater the distance from a harvested plant to its neighbor, the greater the grain yield would be. Therefore, the sum of measurements 1 and 2 was used as a measure of this. That would relate closely to a field situation in which several different plant populations were studied--the lowest populations would have the largest ears.

Similarly, if the harvested plant were located very near another plant, competition would result in a lower yield no matter how far it might be to the next plant. Therefore, the absolute value of the difference between measurements 1 and 2 was used as a measure of that effect. In order to compensate for large skips or missing plants in the two adjacent rows, the same reasoning was used for measurements 3 and 4 and 5 and 6.

When looking at the results, a slightly positive relationship was evident between the sum of measurements 1 and 2 and their absolute difference. This would seem logical since, the greater the distance to one of the adjacent plants (probably the result of a seed not emerging) the greater the absolute difference between that measurement and the measurement to the other adjacent plant within the row. This became a problem of inter-correlation when trying to relate to plant yields. Several attempts were made in the regression analyses to take this into consideration but none improved the r^2 significantly.

Multiple regression analyses were run using the SPSS statistical program (19). The first analysis performed, related grain yield only to the sum of 1 and 2 and their absolute difference. The second analysis included the measurements to the adjacent rows in an attempt to pick up more of the yield variability. The results are shown in Table 10.

A positive coefficient for B_1 was expected with that variable accounting for most of the yield variability. This was generally the case, but at no time did this variable account for more than 13.1 percent of the yield variability. A negative regression coefficient was also expected for B_2. This was the case except for Funks G-4444 and DeKalb XL 390 at Manhattan. A possible reason for this has been discussed in previous sections. The absolute difference between measurements 1 and 2 accounted for less than 1.5 percent of the yield variability in all cases except that of Funks G-4444 at Manhattan where it accounted for 3.5 percent. However, the regression coefficient was positive for that analysis indicating that the larger the absolute difference, the larger the yield.

Table 10. Multiple regression analyses of the effect of spacing to neighboring plants on individual plant yield for all hybrids and locations.

Hybrid	r^2	A	B_1	r^2 change	B_2	r^2 change	B_3	r^2 change	B_4	r^2 change	B_5	r^2 change	B_6	r^2 change
Manhattan														
Funks G-4444	.135	86	1.08	.100	0.86	.035								
	.163	207	1.07	.096	0.81	.034	0.16	<.001	-1.39	.007	-0.92	.010	1.38	.018
BoJac X-56	.002	179	0.15	<.001	-0.24	.002								
	.018	-158	0.24	<.001	-0.26	.002	1.99	.010	-1.76	.005	0.19	<.001	-0.90	<.001
Pioneer 3195	.057	154	0.90	.051	-0.37	.006								
	.079	389	0.84	.051	-0.32	.007	-1.28	.007	0.42	.007	-0.25	<.001	1.44	.007
DeKalb XL 390	.047	141	0.39	.036	0.66	.012								
	.061	261	0.25	.034	0.79	.013	-0.04	<.001	0.31	.002	-0.77	.002	1.74	.010
Ashland														
Pioneer 3195	.122	121	1.55	.120	-0.28	.002								
	.156	-86	1.58	.131	-0.17	.001	0.46	.002	-0.62	<.001	0.85	.023	0.15	<.001
Powhattan														
BoJac X-56	.095	1	1.19	.087	-0.58	.009								
	.155	-554	1.29	.075	-0.68	.008	1.41	.024	-0.10	.003	2.11	.014	-2.89	.031

A---Constant

B_1--Regression coefficient of the variable for the sum of measurements 1 and 2.
B_2--Coefficient of the variable for the absolute value of the difference between measurements 1 and 2.
B_3--Coefficient for the sum of 3 and 4.
B_4--Coefficient for the absolute value of the difference between 3 and 4.
B_5--Coefficient for the sum of 5 and 6.
B_6--Coefficient for the absolute value of the difference between 5 and 6.

overall r^2--The amount of individual plant yield variability that is accounted for by the regression equation

r^2 change----The amount of individual plant yield variability that is accounted for by including that variable in the regression equation.

SUMMARY AND CONCLUSIONS

Standard deviation of spacing as a measure of within-row variability generally was negatively related to grain yield. This effect was more apparent on some hybrids and locations than others. Corn hybrids probably need to be planted thick enough to insure competition before any yield increase can be seen as a result of more precise planting.

Dryland corn seemed to respond more consistently than irrigated corn even though the yield level of dryland corn was lower. This indicates the necessity of spacing precision when conditions are such that moisture may be limiting.

Soil texture doesn't seem to affect the relationship between standard deviation of spacing and yield. Past results that indicated otherwise may have been caused by any number of other factors which include management practices and climatic differences. A negative relationship between standard deviation of spacing and yield existed if the corn crop was optimally managed. This relationship, however, probably doesn't account for more than 5 percent of the yield variability. Results from one hybrid at certain locations may indicate a larger percentage than this, but in most cases, it is considerably less. All these results point to the extreme difficulty of pinpointing the exact contribution to yield that precise planting would have.

The individual plant yield spacing study made this problem very evident. The contribution of a variable measuring increased precision showed no contribution to yield of more than 1 percent. A variable which essentially represented plant population was much more effective in showing its contribution to yield. Even so, this variable accounted for no more than 13 percent of the yield variability and often less.

It seems logical that increasing the precision of plant spacings should increase yield, but it appears that this is true only to a limited extent and depends on other crop management factors as well. Further study could help identify the extent of yield increases if care is taken in controlling all other external factors. No great yield increase will result from increasing planting precision. However, yield increases obtained from more precise planting could be economically significant even if not statistically significant.

ACKNOWLEDGMENTS

I would like to express my deepest appreciation to Dr. Richard Vanderlip for his guidance and patience during my course of study. Without him, I may not have had this chance at a career in Agronomy. I would also like to thank all my fellow graduate students who have been such a big help: Dr. Al Praeger, John Gardner, Sam Jaiyesimi, Bahkt Roidar Khan, Mark Jacques, Joe Gelroth, and others who have assisted since the field work was completed.

I would especially like to thank my wife, Sheryl. She never goaded me, but always gave me assistance any time I needed it. For this I will always be grateful.

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THE EFFECT OF WITHIN-ROW SPACING VARIABILITY ON GRAIN YIELD OF CORN, ZEA MAYS L.

by

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B. S., South Dakota State University, 1971

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1978

Corn is the most productive feed grain in the world. Research over the years has contributed much to this present day status. Many cultural practice studies have been conducted on how inter-row spacing affects corn yields and a few studies indicate that within-row spacing also affects yields. But most of the latter results were extrapolated from data derived from inter-row spacing experiments.

The objective of this study was to determine the extent of any effect within-row spacing variability had on grain yield. This study was conducted under both dryland and irrigated conditions at five locations in northeast Kansas. Also, the effect of soil type was studied at one of these locations. Four corn hybrids of differing relative maturities were planted by hand to a uniform stand in 76.2 cm rows adjacent to machine-planted rows of the same width. Data were taken from 3.05 meter sections of row with exactly the same number of plants in both hand- and machine-planted rows. After measuring distances between individual plants within these subplots, the standard deviation of spacing was calculated for each row section as a measure of within-row variability. Yields from harvested subplots were analyzed by regression analysis with standard deviation of spacing as the independent variable.

Six spacing measurements were taken on individual plants at three of the locations. Combinations of these spatial measurements were used as independent variables in multiple regression analyses with individual plant grain yield as the dependent variable.

Results from the subplot data generally showed a negative relationship between yield and standard deviation of spacing with statistical significance to the five percent level in half of the experiments. In none of the individual hybrid-location results did standard deviation of spacing account for more than 17.3 percent of the yield variability. In most cases this measure of within-row variability accounted for much less. This means that in all cases at least 82.7 percent of the yield variability was not accounted for, even though plant population was held constant in the analyses.

The dryland locations seemed to be more consistent than the irrigated locations in showing a negative relationship. Other factors were evidently influencing the relationship between yield and standard deviation of spacing. No significant relationship was obtained between yield and standard deviation of spacing for the Funks G-4444 hybrid, except at Manhattan, probably as the result of too little inter-plant competition. DeKalb XL 390 had great yield variability over all locations probably due to genetic nonuniformity. Management and other factors must be at an optimum in order to observe the negative relationship between yield and within-row variability.

For the individual plant study the sum of two measurements to each adjacent plant within the row and their absolute difference were used as variables in the multiple regression analyses. The sum of the measurements acted as a measure of plant population, while the absolute difference measured the spacing variability within the row. No more than 1.0 percent of the yield variability was accounted for by the variable measuring accuracy of spacing within the row. The sum of the measurements accounted for no more than 13.1 percent of the yield variability.

In the case of the two hybrids mentioned previously, the coefficient for the difference would suggest that the greater the variability of spacing within the row, the higher the plant yield would be. Other measurements to plants in adjacent rows contributed nothing consistent to the understanding of spatial relationship and plant yield.