RESPONSE OF TWO CORN (*ZEA MAYS* L.) HYBRIDS TO ROW SPACING AND PLANT POPULATION

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ABSTRACT

RESPONSE OF TWO CORN (Zea mays L.)
HYBRIDS TO ROW SPACING AND PLANT POPULATION

by Julius Alani B. Oyedokun

Two corn hybrids that are 50% related in genotype and differing in plant height (based on previous observations) were used to study the effects of four row spacings and five plant populations on total yield, components of yield, maturity, lodging, leaf area, and light inerception. Soil and environmental conditions were conducive to good corn production in 1967.

The average difference in height, 6.4 inches, between the two corn hybrids was not significant. Isogenic hybrids with more of a difference in height are needed to adequately assess the importance of plant height in corn production.

The shorter hybrid, Michigan 500-2x, was higher yielding than the slightly taller hybrid, Michigan 463-3x. Most of the yield components tended to be larger for 500-2x.

Yields ranged from 84.7 to 175.6 bushels per acre depending on the specific combination of hybrid, plant population and row spacing. The highest yield, 175-6 bushels, was obtained with Michigan 500-2x at a population of 28,000 plants per acre in 20-inch rows. Ear weight was 0.463 pound.

Plant population had the greatest effect on yield, row spacing next, and then hybrid. With increasing population, yields increased more in narrow rows (30- and 20-inches) than in 38-inch rows. Soil compaction by tractor wheels at planting depressed yields in 15-inch rows.

Plant population significantly affected six of eight yield components while row spacing effects were significant for only two of the eight components. Correlations with yield were small but significant for five components: kernels per row (.21), total kernels per ear (.21), ear length (.18), ear weight (.28), and kernel weight (.32). The multiple correlation for yield with all components was 0.41.

Leaf area portion (LAP) was significantly correlated with yield. Differences due to hybrids and populations were small and not significant. LAP on a per plant basis did not decrease with increased population and, consequently, leaf area per acre increased. The two highest yielding spacings, 30- and 20-inch rows, had higher LAP values than the lower yielding spacings, 38- and 15-inch rows.

Light interception increased significantly with population for eight of the 11 readings. Light readings were made 7 inches from the row for all spacings and differences due to row spacings were generally not significant. Photographs of leaf shadows did show a difference. Light readings should have been taken in the center of the inter-row space.

Maturity and lodging were not significantly affected by plant population and row spacing.

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INTRODUCTION

Maximum crop production is obtained with the optimum combination of superior agronomic practices and crop varieties for the existing weather and soil conditions.

Corn (Zea mays L.), a leading grain in the world, has been grown traditionally in rows spaced 36 to 42 inches part and at plant populations ranging from about 5,000 to 24,000 or more plants per acre. Adapted hybrids and heavy nitrogen application along with adequate phosphorus and potassium have advanced corn yields at higher plant densities.

While plant population can be too low, it can also be too high. An increase in plant density may be offset by a decrease in grain yield per plant. A point of balance between increasing density and decreasing yield per plant is reached at the level which produces maximum grain yield per unit land area. Factors that determine this balance point are plant population, soil fertility, soil moisture, seasonal conditions, and corn hybrids grown.

Recently, interest in the potentials for higher yields with narrower row spacings has increased. In narrow rows the plants are spaced more nearly equidistant over the land area. Close rows and adequate stands may provide a more uniform crop canopy and less sunlight reaches the soil, with less evaporation of moisture from the soil surface. Weed problems may be reduced since there should be more shading of the soil with less light available for weed growth. More uniform corn root distribution may increase uptake of plant nutrients.

There is some speculation, with little critical data, that short hybrids may yield better than taller hybrids in narrow rows. Less mutual leaf shading is expected with short hybrids. Comparison of short and tall hybrids with different genotypes cannot be expected to provide a critical evaluation of the potential advantages for short plant types. Iso-genic hybrids differing only in plant heights are needed to remove the effect of genotype and to provide more precise estimates of the effects of plant height, per se. Completely iso-genic hybrids of this type are not currently available except for those involving recessive dwarfing genes, brachytic-2 and compact. Critical comparison of dwarf versus normal height isogenic hybrids have not been made in population x row spacing experiments (17, 20, 21, 22, 23).

Two hybrids that are 50% related in genotype and differing in plant height were used to study the effects of various row spacing and plant population combinations on total yield, components of yield, maturity, lodging, leaf area, and light interception. A single cross hybrid, Michigan 500-2x (W64A x Oh 43), and a three-way hybrid, Michigan 463-3x [(Oh51AxMs67) xW64A] were used.

LITERATURE REVIEW

Numerous experiments have been conducted in many states and the literature reviewed (8, 12, 26, 29, 34) to study the effects of plant population on corn production. Less extensive research has been conducted on row spacing effects and interction with population and hybrids.

Richey (26) summarized early studies on plant populations and concluded that the optimum stand of corn was heavier as one proceeded from genetically larger to smaller plants, from lower to higher moisture supply, and from low to high soil productivity.

Dungan et al. (8) later summarized many of the row spacing and plant population experiments and found that the results were inconclusive. Great variation was encountered from year to year and from location to location, due to climatic and environmental conditions.

Rossman and Cook (29) concluded that recommended plant populations are 50 to 100% higher with current hybrids and fertility programs than those recommended in the days of open pollinated varieties and low rate of fertilizer. Published results of comparisons of narrow rows (18-21 inches) with conventional 36- to 42-inch rows showed variable yield increases of 0 to 93 percent. Most of the increases ranged from 3 to 20 percent. Plant population had a greater effect on corn yield than row spacing.

Lang et al. (16) observed that hybrids respond differentially to plant populations and soil fertility.

Denmead et al. (7) estimated that 24-inch row spacings might increase energy available for photosynthesis by 15-20 percent compared to 40-inch rows.

Bryan et al. (3) in Iowa found that corn spaced 21x21 inches yielded significantly more than corn spaced 42x42 inches in two of four years. Differences for the four years, however, were not significant.

Stickler and Laude (33) found little difference in yield from 20-inch or 40-inch row spacings when weed growth was eliminated. Yield was drastically reduced in narrow rows without weed control.

Pendleton and Seif (22) evaluated 20-, 30-, and 40-inch rows at varying plant populations with a brachytic-2 dwarf corn, and found that highest yields were obtained with 30-inch row spacing. Narrow rows required slightly high population for maximum yield than did 40-inch rows.

Pfister (24) obtained a 27 bushel per acre increase from 20- x 20-inch versus 40- x 40-inch row spacing.

Hoff and Mederisk (14) found that equidistant planting (18-1/2 inch rows) outyielded 42-inch rows by 7 to 10 bushels per acre. They suggested that individual plant competition in narrow rows contributed to increased grain yield.

Colville and Burnside (5) found mean yields of 146 and 91 bushels per acre for irrigated corn planted in 20- x 20-inch and 40- x 40-inch row spacings, respectively, with 15,680 plants per acre.

Stickler (32) reported a yield advantage of 5% in non-irrigated corn from 20-inch rows over 40-inch rows. He obtained 6% increase under irrigation. Non-irrigated corn yielded best at 16,000 plants per acre. Under irrigation, highest yields were obtained with either 20,000 or 24,000 plants per acre.

Yao and Shaw (36) obtained significantly higher yield from 21-inch spacing than from 32-inch and 42-inch row spacing. They found no difference between 32-inch and 42-inch spacings. In their opinion, higher yield from the 21-inch spacing resulted from more even distribution of leaves to intercept more radiant energy.

MATERIALS AND METHODS

Two corn hybrids, a single cross hybrid Michigan 500-2x(W64AxOh43) and a three-way hybrid Michigan 463-3x [(Oh51AxMS67)xW64A], were compared in 1967 to determine their responses to row spacing and plant population. Michigan 500-2x is relatively short in plant height and Michigan 463-3x is slightly taller. The soil was a Conover clay loam that has been in continuous corn for 12 years. The experiment was conducted at the Crop Science Research farm near East Lansing in Ingham County, Michigan.

Five hundred and sixty-one pounds of 10-20-20 and 450 pounds NH_4NO_3 per acre were broadcast before planting for a total of 206-112-112 pounds N-P_2O_5-K_2O (206-49.3-93 pounds N-P-K) per acre. Soil test (pH = 6.5, P = 73 very high, K = 191 high), before applying fertilizer, were favorable for corn production.

Atrazine was applied preplanting to control weeds with no subsequent cultivation. Relatively good season-long weed control was obtained.

Row spacings were 15-, 20-, 30-, and 38-inches. Plant populations were 12,000, 16,000, 20,000, 24,000 and 28,000 plants per acre.

A split-split plot design was employed with row widths as main plots, hybrids as sub-plots, and plant populations as sub-sub-plots. There were forty treatment combinations in a factorial arrangement with four replications.

Plots were hand planted on May 13 with excess seed and later thinned to desired stands. Plots were three rows, 30 feet long, oriented east-west.

The center row of each plot was hand harvested on September 30. Moisture content was determined on an ear basis, cob plus grain. Ear weights were converted to bushels per acre of shelled corn at 15.5% moisture. Corrections for stand were made on a few plots where needed.

Light readings in foot candles were obtained with a Weston Illumination meter-model 756 quartz filter. Readings were taken once a week at 8 a.m., 12 noon, and 4 p.m. at a fixed location each time in all plots of two replications, starting when corn was approximately 16 to 18 inches high and continued until pollination. Two light readings were taken for each plot. One was made above the leaf canopy to represent available radiation. The other was taken below the leaf canopy, about six inches above the soil line and about seven inches from the row. The difference between the two readings was used as a measure of the intercepted radiant energy by the leaf canopy. Lag time of the light meter appeared to be inconsistent on occasions. Thus, the results from light measurements may not be accurately representative of the conditions and should be interpreted with caution.

"Leaf Area Portion" (LAP) was determined in all plots at three stages of growth. On July 3 and July 13, the first leaf below the whorl from each of five plants, selected at random from the center row, was removed and measured. At silking, August 5, the first leaf, below and opposite the ear from five plants was measured. The formula, length x width x 0.75, (19), was used to determine LAP. An average for the five leaves was used for the plot value.

Plant height, silking dates, stalk lodging, and yield components (ear length, number of kernel rows, number of kernels per row, weight per 200 kernels, kernels per ear, and shelling percent) were determined.

Plant height was the average distance from the soil surface to the tips of the tassels.

A plot was considered silked when an estimated 50% of the plants had silked. Plants broken below the ear were counted as stalk lodged at harvest.

Five ears selected at random from each plot were used to determine average values per ear for yield components. According to Leng (18) primary components of grain yield are number of kernels per row. Secondary or complex components are weight of grain per ear, and number of kernels per ear.

EXPERIMENTAL RESULTS

Total rainfall, 18.38 inches for April to September, was about normal (18.17 inches) in 1967, Table 1. June, July, and August total rainfall was 11.19 inches compared to the normal 8.97 inches. A dry period of about one month (July 19 to August 19) occurred during which there was no "effective rainfall" (.5 inch or more). Above normal rain during late June reduced the effects of this prolonged dry period.

Plant heights averaged 74.8 and 81.2 inches for the two hybrids, Michigan 500-2x and Michigan 463-3x, respectively, Table 2. The average difference in plant height, 6.4 inches, was less than anticipated based on previous observations of these two hybrids. More extreme differences in plant height are needed to adequately assess the importance of plant height, per se, in corn production.

Michigan 500-2x was higher yielding (123.5 vs. 111.2 bushels), slightly later in maturity (3 days later in silking and 3% higher moisture content at harvest), and exhibited less lodging than Michigan 463-3x. Leaf Area Portion (LAP) for 500-2x was slightly lower than 463-3x at the first two measurements but slightly larger at silking. However, these differences in LAP were not significant. Most of the yield components (number of kernel rows, kernels per row, kernels

Table I. Precipitation data obtained at Lansing weather station, 1967.

April		May		June		July		August		September	
Date	Inches	Date	Inches	Date	Inches	Date	Inches	Date	Inches	Date	Inches
4/3	1.12	5/2	.16	6/7	.18	7/3	.02	8/18	.09	9/23	.90
4/6	.47	5/4	.11	6/8	.60	7/19	.83	8/19	.79	9/24	.13
4/7	.04	5/8	.18	6/10	.40	7/21	.31	8/27	2.10	9/26	.47
4/10	.28	5/9	.22	6/12	.05	7/25	.02	8/30	.47	9/27	.37
4/15	.34	5/11	.32	6/14	.48	7/26	.15			9/28	.07
4/17	.37	5/15	.05	6/15	.02	7/31	.30			9/30	.54
4/21	.57	5/22	.08	6/17	.50						
4/22	.34	5/24	.06	6/22	2.12						
				6/26	1.54						
				6/29	.18						
				6/30	.04						
TOTAL	3.53		1.18		6.11		1.63		3.45		2.48
Normal	2.87		3.73		3.34		2.58		3.05		2.60
Deviation from Normal	+.66		-2.55		+2.77		- .95		+ .40		- .12

Total April-September = 18.38 inches
Normal Total April-September = 18.17 inches
Total deviation from normal = + .21 inches

Total June, July, August = 11.19 inches
Normal June-August = 8.07 inches
Deviation from normal + 2.22 inches

Table 2. Comparison of the means for several plant and ear characteristics for two corn hybrids, Michigan 500-2x and Michigan 463-3x

Characteristic	Michigan 500-2x	Michigan 463-3x	Difference
Plant height, inches	74.8	81.2	6.4
Days from planting to 50% silked	80.0	77.0	3.0**
Leaf area portion, cm^2., 50 days after planting	282.4	299.6	17.2
Leaf area portion, cm^2., 60 days after planting	439.9	454.2	14.3
Leaf area portion, cm^2., at silking	598.8	568.5	30.3
Lodging %	1.9	5.6	3.7*
Moisture content in ears	44.9	41.9	3.0**
Number of kernel rows	16.0	15.0	1.0**
Kernels per row	38.0	36.0	2.0*
Total kernels per ear	600.0	556.0	44.0**
200-kernel weight, grams	56.9	56.3	0.6
Ear Length (cm.)	17.4	16.4	1.0*
Ear weight, pound	0.49	0.44	0.05*
Shelled corn per ear, grams	165.7	154.1	11.6
Yield, average of all treatments	123.5	111.2	12.3*

* Significant at 5% level of probability

** Significant at 1% level of probability

per ear, ear length, ear weight, and shelled weight per ear) tended to be larger for 500-2x. Kernel weight was similar for both hybrids.

Summarized results for yield and its components are presented in Table 3, with means for moisture content, lodging, LAP, and days from planting to 50% silked in Table 4. Analysis of variance are presented in Table 6.

Yield. The highest yield, 175.6 bushels per acre, was obtained with Michigan 500-2x in 20-inch rows at 28,000 plants per acre.

Main effects, row spacings, hybrids, and populations, were all significant, Table 6. Plant population had the greatest effect on yield, row spacing next, and then hybrid. The only significant interaction was row spacing x population. In 38-inch rows, yields increased much less with increasing population than in narrower rows of 30, 20, and 15 inches, Table 6 and Figure 3.

The two hybrids tended to respond alike to population and row spacing changes, Table 3 and Figures 1 and 2. In general, yields for both hybrids increased as population increased and as row spacing was narrowed.

Table 3. Means for yields and components of yield (number of kernel rows, number of kernels per row, ear length, ear weight, shelled grain per ear, kernel weight, kernels per ear, and shelling percentage) for two corn hybrids grown at five plant populations and four row spacings.

Row Spacing (Inches)	MICH. 500 - 2X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	MICH. 463 - 3X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	Row Spacing Average
					YIELD (Bushels per acre) at 15.5% moisture								
38	93.7	102.5	99.8	117.2	116.4	105.9	91.5	88.8	108.2	84.7	105.3	95.7	100.8
30	97.9	130.0	134.9	150.5	145.9	131.8	92.4	102.6	117.7	138.9	141.1	118.5	125.2
20	114.4	136.0	151.7	159.1	175.6	147.4	87.3	108.2	122.4	123.2	139.9	116.2	131.8
15	76.9	92.3	106.2	123.7	145.3	108.9	105.2	86.5	113.1	126.9	140.5	114.4	111.7
Average	95.7	115.2	123.2	137.6	145.8	123.5	94.1	96.5	115.4	118.4	131.7	111.2	118.4
& Increase	--	20.4	28.7	43.8	52.4		--	2.6	22.6	25.8	40.0		
					NUMBER OF KERNEL ROWS								
38	17	15	16	16	16	16.0	15	15	16	15	15	15.2	15.6
30	16	16	16	16	16	16.0	16	16	16	15	16	15.8	15.9
20	15	16	16	16	16	15.8	16	16	15	16	15	15.8	15.8
15	16	15	16	17	16	16.0	15	15	15	16	15	15.2	15.6
Average	16.0	15.5	16.0	16.3	16.0	16.0	15.5	15.5	15.5	15.5	15.5	15.5	15.7

Table 3. Continued -

Row Spacing (Inches)	MICH. 500 - 2X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	MICH. 463 - 3X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	Row Spacing Average
NUMBER OF KERNELS PER ROW													
38	41	40	34	35	34	36.8	39	37	37	34	34	36.2	36.5
30	43	41	36	37	34	38.2	40	38	37	38	33	37.2	37.7
20	43	43	41	39	37	40.6	37	39	36	32	35	35.8	38.2
15	40	35	36	34	36	36.2	40	34	36	33	30	34.6	35.4
Average	41.8	39.8	36.8	36.3	35.3	38.0	39.0	37.0	36.5	34.3	33.0	36.0	37.0
200 KERNEL WEIGHT (Grams)													
38	57.5	52.0	52.1	57.1	54.9	56.7	57.1	54.4	57.4	55.8	57.2	56.4	56.6
30	63.9	59.7	55.7	61.5	56.3	59.4	63.0	58.9	60.5	59.1	55.0	59.3	59.4
20	63.3	60.9	61.3	58.6	55.0	59.8	58.2	57.3	58.2	51.9	59.2	57.0	58.4
15	53.2	51.1	50.6	50.4	52.2	51.5	55.4	54.6	50.9	56.9	45.1	52.6	52.0
Average	59.5	58.4	54.9	56.9	54.6	56.9	58.4	56.3	56.8	55.9	54.1	56.3	56.6
TOTAL KERNELS PER EAR													
38	682	616	542	546	531	583.4	585	578	576	499	523	552.2	567.8
30	695	647	578	583	528	606.2	633	588	587	577	521	581.2	593.7
20	657	682	662	615	580	639.2	592	601	544	503	543	556.6	597.9
15	612	529	563	567	586	571.4	610	534	539	535	449	533.4	552.4
Average	661.5	618.5	586.3	577.8	556.3	600.1	605.0	575.3	561.5	528.5	509.0	555.9	578.0

Table 3. Continued -

Row Spacing (Inches)	MICH. 500 - 2X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	MICH. 463 - 3X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	Row Spacing Average
							SHELLING PERCENTAGE						
38	74.7	74.8	71.7	77.6	74.5	74.7	77.9	77.1	79.3	74.0	77.2	77.2	75.9
30	73.9	73.7	71.7	76.7	72.9	73.8	74.1	78.0	76.2	77.9	73.4	75.9	74.9
20	74.0	77.6	75.7	73.7	75.1	75.2	78.0	76.3	78.4	74.1	74.7	76.3	75.8
15	74.2	67.8	69.4	69.3	74.4	71.0	74.5	78.5	73.6	78.1	78.1	76.0	73.5
Average	74.2	73.5	72.1	74.3	74.2	73.7	76.1	77.5	76.9	76.0	75.3	76.4	75.0
							EAR LENGTH (cm.s)						
38	18.9	17.9	15.7	15.4	15.7	16.7	17.3	16.6	16.5	15.8	15.7	15.7	16.4
30	19.9	18.6	17.1	16.7	15.8	17.6	18.4	17.1	17.6	17.0	15.7	17.2	17.4
20	20.0	19.3	18.8	17.6	17.0	18.5	17.3	17.6	16.3	15.0	16.2	16.5	17.5
15	17.7	16.8	17.5	16.3	16.5	17.0	18.2	16.2	15.7	15.3	13.6	15.8	16.4
Average	19.1	18.2	17.3	16.5	16.3	17.5	17.8	16.9	16.5	15.8	15.3	16.5	17.0
							EAR WEIGHT (Pounds)						
38	0.577	0.523	0.420	0.397	0.412	0.466	0.467	0.439	0.444	0.427	0.412	0.438	0.452
30	0.624	0.557	0.499	0.481	0.424	0.517	0.539	0.481	0.506	0.470	0.416	0.482	0.500
20	0.610	0.579	0.576	0.516	0.463	0.549	0.483	0.502	0.439	0.398	0.467	0.458	0.503
15	0.448	0.444	0.465	0.419	0.447	0.445	0.507	0.402	0.409	0.396	0.302	0.403	0.424
Average	0.565	0.526	0.490	0.453	0.437	0.494	0.499	0.456	0.450	0.423	0.399	0.445	0.470

Table 3. Continued -

Row Spacing (Inches)	MICH. 500 - 2X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	MICH. 463 - 3X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	Row Spacing Average
						SHELLED GRAIN PER EAR (Grams)							
38	195.3	177.6	137.5	140.2	139.7	158.1	164.5	153.3	159.0	143.2	145.1	153.0	155.5
30	209.6	187.8	162.2	167.7	142.0	173.9	180.8	170.9	176.1	165.2	137.7	166.1	170.0
20	204.7	203.5	197.7	169.0	158.5	186.7	170.8	173.9	154.9	134.4	157.7	158.3	172.5
15	151.3	138.9	147.2	147.2	150.9	144.1	170.1	142.5	136.8	140.4	104.0	138.8	141.5
Average	190.2	177.0	161.2	161.2	147.8	165.7	171.6	160.2	156.7	145.8	136.1	154.1	159.9

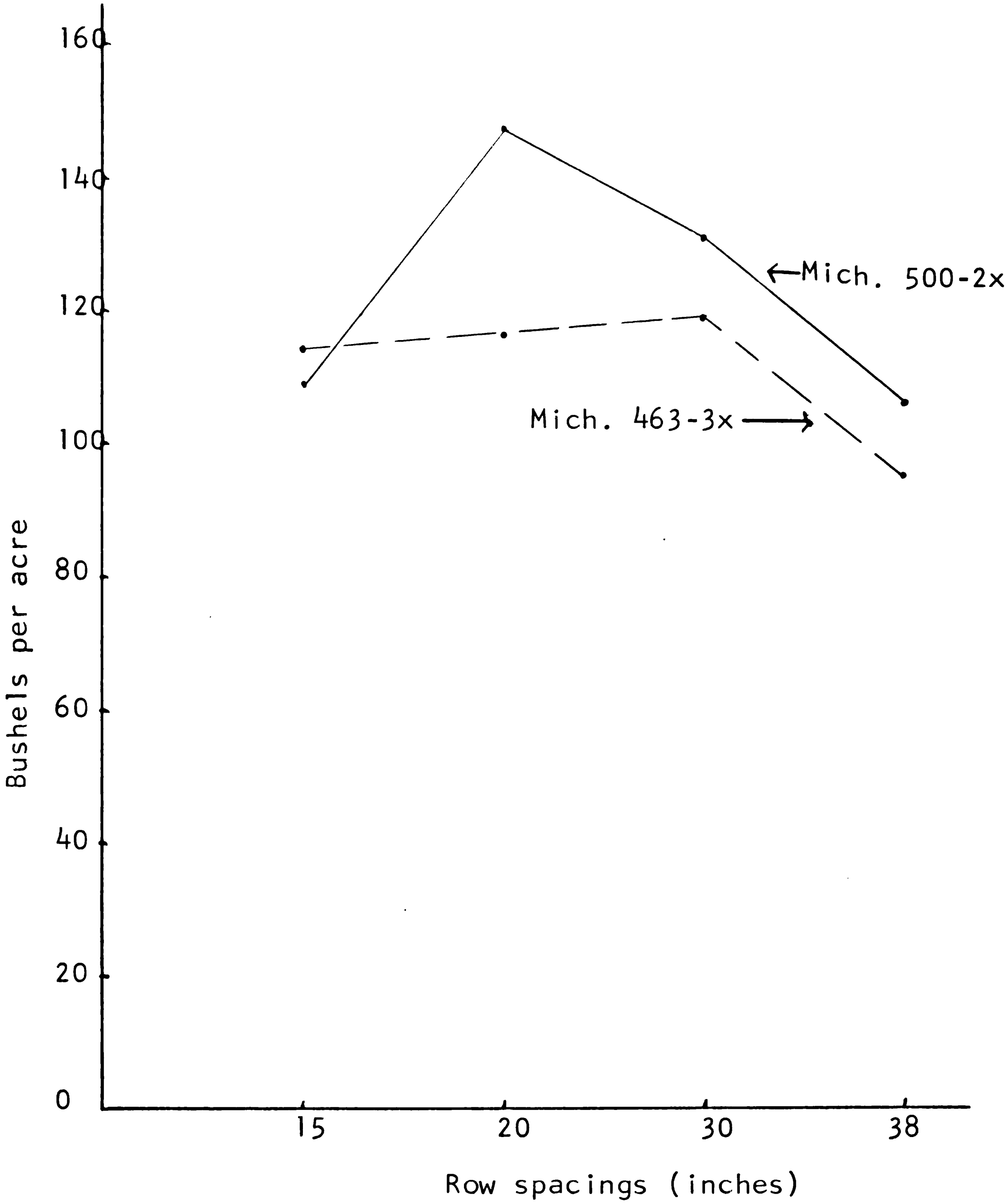

Figure 1. Yield response of two corn hybrids to four row spacings

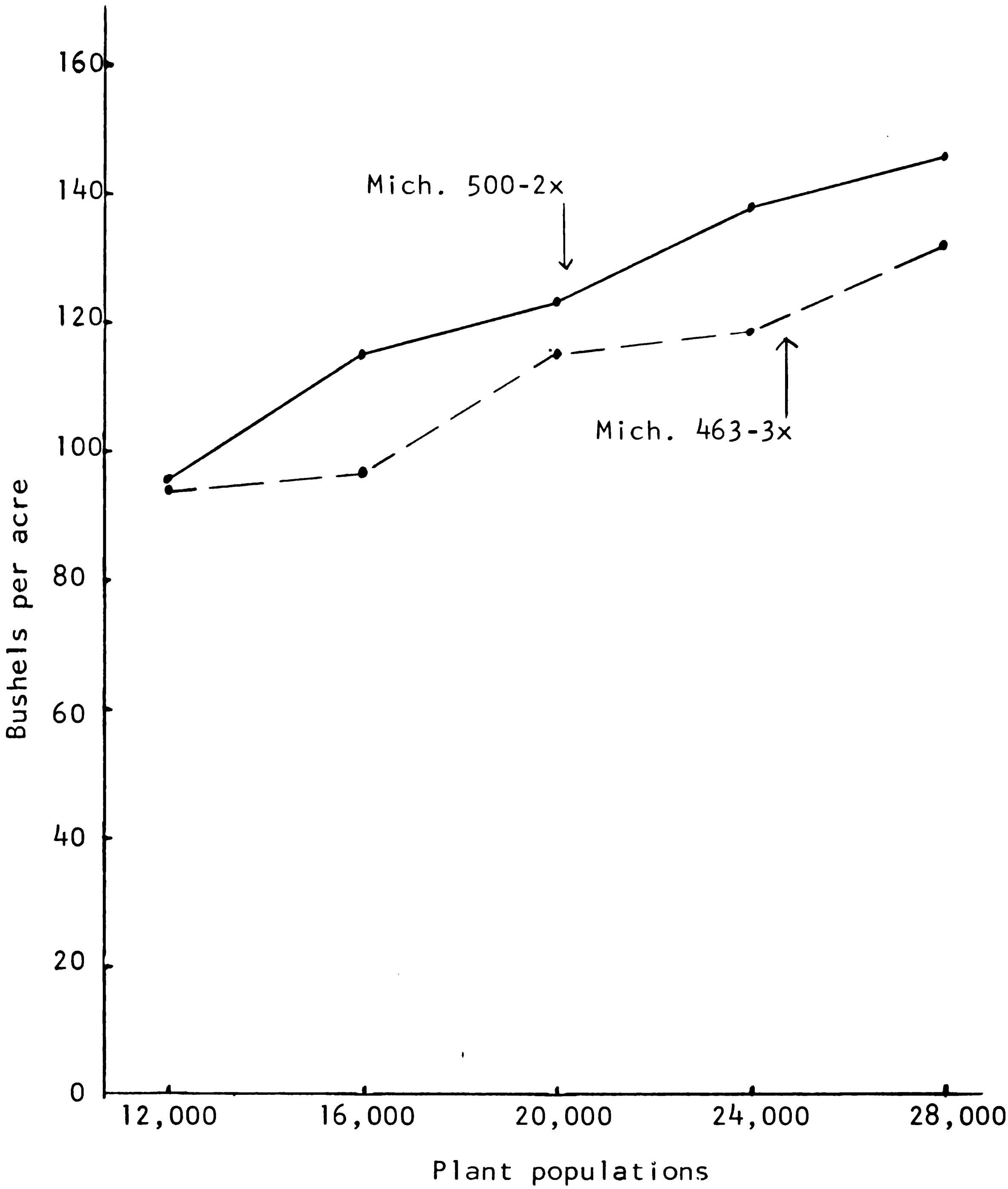

Figure 2. Yield response of two corn hybrids to five plant populations

Table 4. Means for moisture content at harvest, lodging, leaf area portion (LAP), and days to 50% silked for two corn hybrids grown at five plant populations and four row spacings.

Row Spacing (Inches)	MICH. 500 - 2X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	MICH. 463 - 3X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	Row Spacing Average
							% MOISTURE CONTENT IN EARS						
38	43.3	43.2	45.0	44.2	43.8	43.9	40.0	40.9	41.3	42.5	42.1	41.4	42.6
30	43.9	43.2	43.8	43.6	44.6	43.8	40.8	41.3	40.5	41.5	42.1	41.2	42.5
20	46.3	43.0	42.7	44.1	45.0	44.2	41.9	40.9	41.5	41.5	41.2	41.4	42.8
15	46.7	50.9	48.8	47.3	45.2	47.7	43.6	43.5	43.7	42.2	44.7	43.5	45.7
Average	45.1	45.1	45.1	44.8	44.7	44.9	41.6	41.7	41.8	41.9	42.5	41.9	43.4
							% LODGING						
38	1.7	1.9	0.5	0.5	1.2	1.2	1.9	3.7	3.8	2.1	7.1	3.7	2.4
30	0.0	0.0	0.7	0.7	1.7	0.6	8.0	1.9	4.4	3.1	4.7	4.4	2.5
20	0.0	0.0	0.0	3.3	1.2	0.9	4.9	5.3	2.4	10.9	3.3	5.4	3.1
15	9.3	7.3	3.7	3.8	1.0	5.0	7.8	9.9	10.6	8.1	8.2	8.9	7.0
Average	2.8	2.3	1.2	2.1	1.3	1.9	5.7	5.2	5.3	6.1	5.8	5.6	3.8

Table 4. Continued -

Row Spacing (Inches)	MICH. 500 - 2X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	MICH. 463 - 3X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	Row Spacing Average
					LEAF AREA PORTION (Leaf (CM.^{2}) - 50 DAYS AFTER PLANTING								
38	286.4	297.6	280.9	277.0	259.1	280.2	313.2	306.0	282.0	298.0	316.7	303.2	291.7
30	309.2	293.7	302.2	307.5	328.5	308.2	302.9	320.6	330.5	306.1	307.8	313.6	310.9
20	332.9	304.9	316.0	298.1	277.2	305.8	286.0	325.4	303.1	260.7	314.7	298.0	301.9
15	228.9	228.0	194.9	257.8	267.3	235.4	281.6	254.0	282.6	299.3	301.6	283.8	259.6
Average	289.4	281.1	273.5	285.1	283.0	282.4	295.9	201.5	299.6	291.0	310.2	299.7	291.0
					LEAF AREA PORTION/ LEAF (CM^2) - 60 DAYS AFTER PLANTING								
38	414.2	436.4	402.2	411.0	424.5	417.7	478.7	495.0	438.3	460.8	456.6	465.9	441.8
30	483.0	460.5	466.9	509.7	455.9	475.2	476.4	475.9	473.4	464.3	464.7	470.9	473.1
20	527.2	481.5	502.8	449.7	430.5	478.3	460.3	485.3	457.5	396.8	482.5	456.5	467.4
15	404.8	384.4	338.9	391.4	422.1	388.3	390.8	404.3	424.8	431.6	465.4	423.4	405.9
Average	457.3	440.7	427.7	440.5	433.3	439.9	451.6	465.1	448.5	438.4	467.3	454.2	447.0
					LEAF AREA PORTION/ LEAF (CM^2) - AT SILKING								
38	549.4	530.6	544.4	537.7	564.0	545.2	550.1	540.7	542.2	528.5	525.0	537.3	541.3
30	653.3	641.5	673.9	677.7	656.5	660.6	614.9	605.3	612.0	587.4	595.9	603.1	631.8
20	688.8	678.9	655.5	648.1	664.9	667.2	608.6	614.0	610.9	571.5	614.1	603.8	635.5
15	558.0	525.6	437.5	517.6	573.3	522.4	534.4	516.7	519.1	537.3	541.0	529.7	526.1
Average	612.4	594.2	577.8	595.3	614.7	598.9	577.0	569.2	571.1	566.2	569.0	568.5	583.7

Table 4. Continued -

Row Spacing (Inches)	MICH. 500 - 2X Plant Population						MICH. 463 - 3X Plant Population						Row Spacing Average
	12,000	16,000	20,000	24,000	28,000	Ave.	12,000	16,000	20,000	24,000	28,000	Ave.	
							DAYS TO 50% SILKED						
38	80	80	81	80	80	80.2	76	77	77	78	77	77.0	78.6
30	79	79	80	79	79	79.2	77	76	77	77	78	77.0	78.1
20	79	78	79	79	79	78.8	77	77	76	76	77	76.6	77.7
15	82	81	82	82	80	81.4	77	79	78	78	79	78.2	79.8
Average	80.0	79.5	80.5	80.0	79.5	79.9	76.8	77.3	77.0	77.3	77.8	77.2	78.6

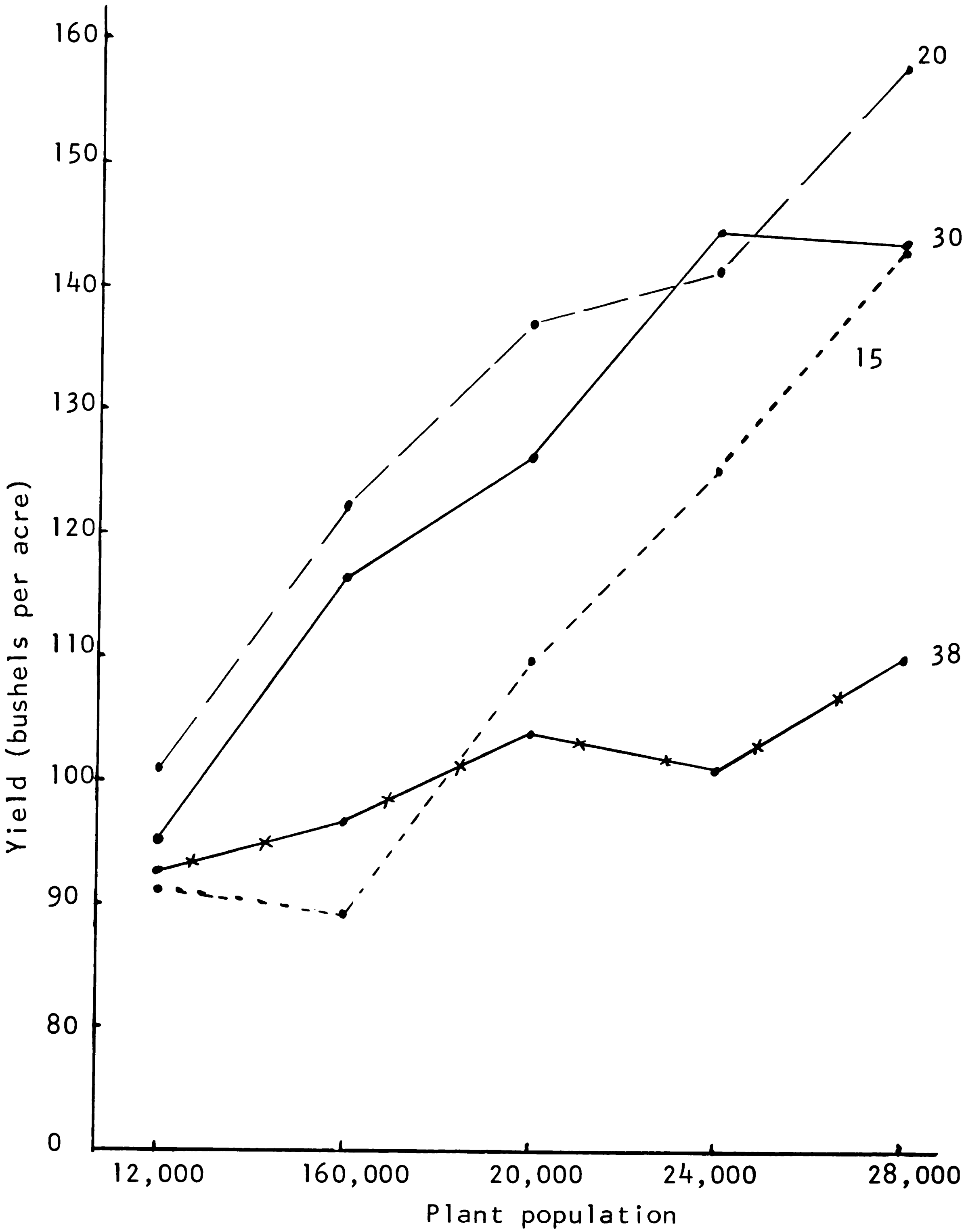

Figure 3. Row spacing x plant population interaction for grain yield

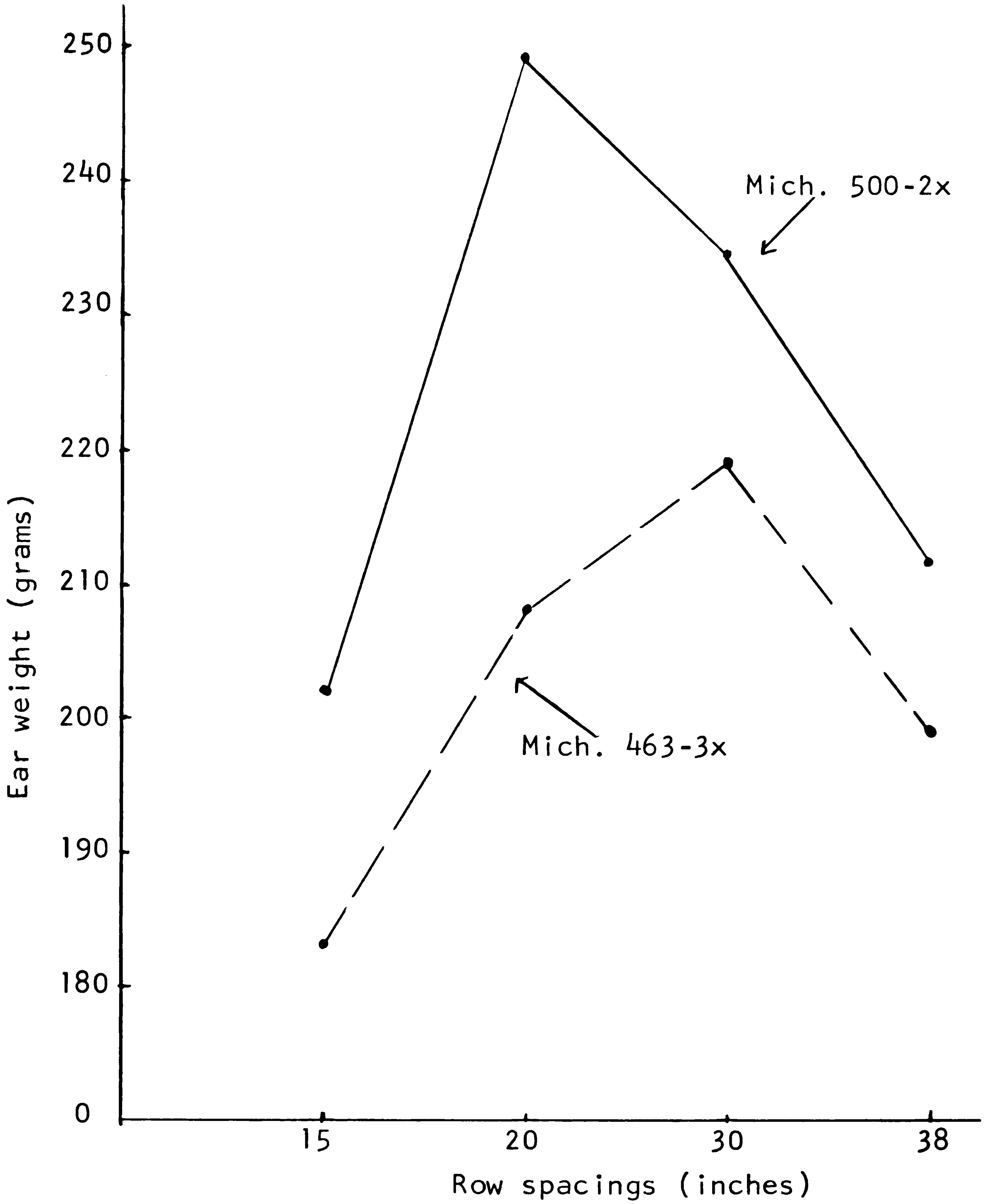

Figure 4. Ear weight of two corn hybrids as affected by four row spacings

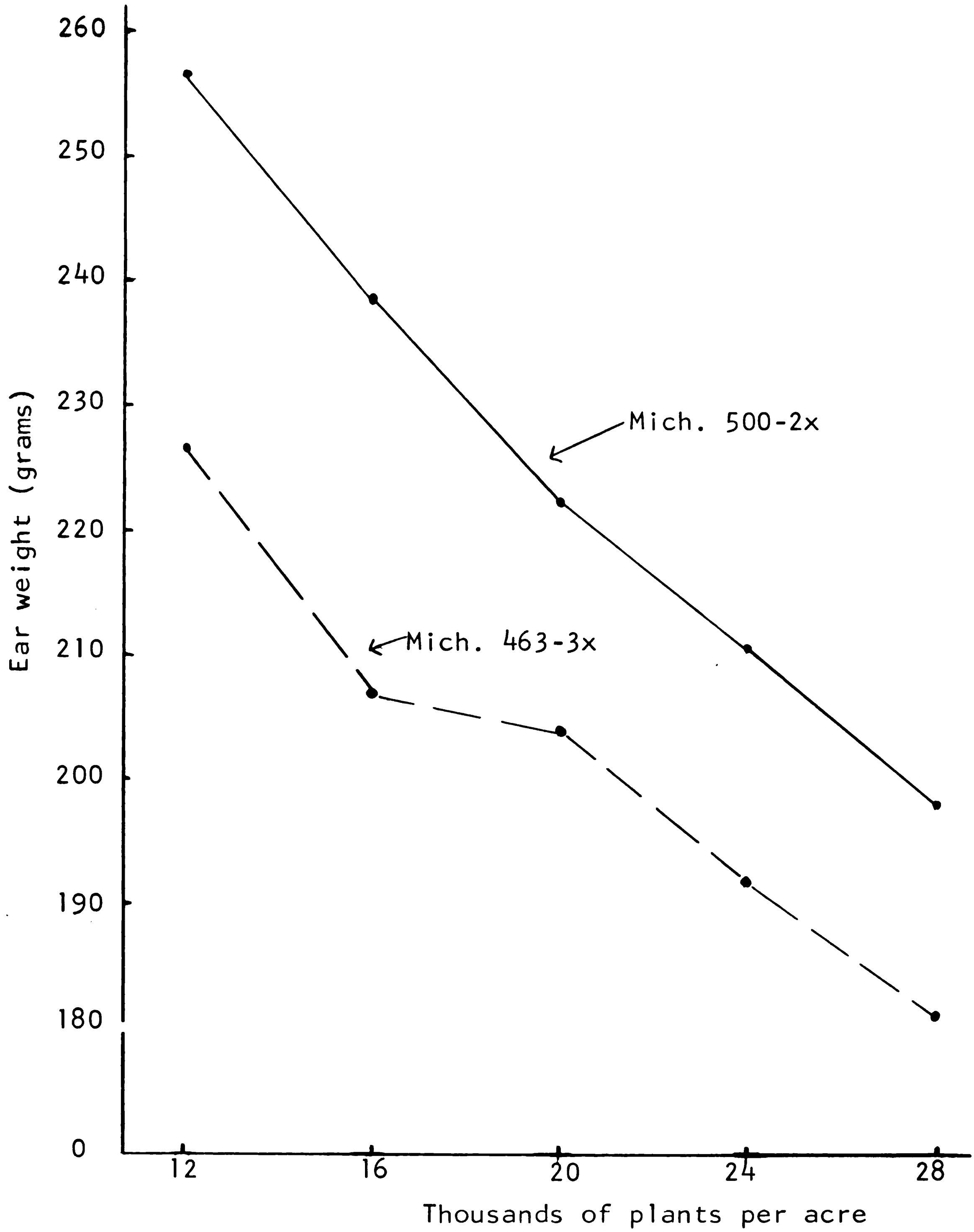

Figure 5. Ear weight of two corn hybrids as affected by five plant populations

Michigan 500-2x averaged 95.7, 115.2, 123.2, 137.6, and 145.8 bushels and Michigan 463-3x averaged 94.1, 96.5, 115.4, 118.4, and 131.7, for populations of 12, 16, 20, 24, and 28 thousand plants per acre, respectively, Table 3. Average yields in 38-, 30-, 20-, and 15-inch rows were 105.9, 131.8, 147.4, and 108.9 for Michigan 500-2x and 95.7, 118.5, 116.2, and 114.4 for Michigan 463-3x. Regressions, Figure 6, indicate that yields of 500-2x increased 3.1 bushels and 463-3x increased 2.4 bushels per 1,000 plant increase in population within the range 12,000 to 28,000 plants per acre.

Average yields for both hybrids were 95.0, 105.9, 119.3, 128.1, and 138.8 bushels for populations of 12, 16, 20, 24, and 28,000, respectively, Table 5. Row spacings of 38-, 30-, 20-, and 15-inches averaged 100.8, 125.2, 131.8, and 111.7 bushels, respectively.

Soil compaction by tractor wheels in 15-inch row plots at planting noticeably delayed seedling emergence. Early seedling growth was slower, stands were less uniform, plants were smaller with less leaf area portion, and yields were reduced. The average yield was 14.4 bushels lower in 15- than in 20-inch rows.

Yield components. Analyses of variance, Table 6, showed that the difference between the two hybrids were significant for six of the eight components measured. Number of kernel rows,

Table 5. Means for yields and components of yield for five plant populations at four row spacings.

Row Spacing (Inches)	PLANT POPULATION 12,000	16,000	20,000	24,000	28,000	Average	ROW SPACING Average
	YIELD (BUSHELS PER ACRE) AT 15.5% MOISTURE						
38	92.6	95.7	104.0	101.0	110.9		
% increase	--	3.3	12.3	9.1	20.0	100.8	100.8
30	95.2	116.3	126.3	144.7	143.5		
% increase	--	22.2	32.7	52.0	50.7	125.2	125.2
20	100.9	122.1	137.1	141.2	157.8		
% increase	--	21.0	35.9	40.0	56.4	131.8	131.8
15	91.1	89.4	109.7	125.3	142.9		
% increase	--	-18.7	20.4	37.5	56.9	111.7	111.7
Average	95.0	105.9	119.3	128.1	138.8		
% increase	--	11.5	25.6	34.8	46.1	117.4	117.4
	NUMBER OF KERNEL ROWS						
38	16.0	15.0	16.0	15.5	15.5	15.6	15.6
30	16.0	16.0	16.0	15.5	16.0	15.9	15.9
20	15.5	16.0	15.5	16.0	16.0	15.8	15.8
15	15.5	15.0	15.5	16.5	15.5	15.6	15.6
Average	15.8	15.5	15.8	15.9	15.8	15.7	15.7

Table 5. Continued -

ROW SPACING (Inches)	PLANT POPULATION 12,000	16,000	20,000	24,000	28,000	Average	ROW SPACING Average
			NUMBER OF KERNELS PER ROW				
38	40.0	38.5	35.5	34.5	34.0	36.5	36.5
30	42.0	39.5	36.5	37.5	33.5	37.8	37.7
20	40.0	41.0	38.5	35.5	36.0	38.2	38.2
15	40.0	34.5	36.0	33.5	33.0	35.4	35.4
Average	40.5	38.4	36.6	35.3	34.1	37.0	37.0
			EAR LENGTH (Cm.s)				
38	18.1	17.3	16.1	15.6	15.7	16.6	16.6
30	19.2	17.9	17.4	16.9	15.8	17.4	17.4
20	18.7	18.5	17.6	16.3	16.6	17.5	17.5
15	18.0	16.5	16.6	15.8	15.1	16.4	16.4
Average	18.5	17.6	16.9	16.2	15.8	17.0	17.0
			EAR WEIGHT (pounds)				
38	.522	.481	.432	.412	.412	.452	.452
30	.582	.519	.503	.476	.420	.500	.500
20	.547	.541	.508	.457	.465	.504	.503
15	.478	.423	.437	.408	.375	.424	.424
Average	.532	.491	.470	.438	.418	.470	.470

Table 5. Continued -

ROW SPACING (Inches)	PLANT POPULATION 12,000	16,000	20,000	24,000	28,000	Average	ROW SPACING Average
			SHELLED GRAIN PER EAR (Grams)				
38	179.9	165.5	148.3	141.7	142.4	155.6	155.5
30	195.2	179.4	169.2	166.5	139.9	170.0	170.0
20	187.8	188.7	176.3	151.7	158.1	172.5	172.5
15	160.7	140.7	142.0	136.4	127.5	141.5	141.5
Average	180.9	168.6	159.0	149.1	142.0	159.9	159.9
			200-KERNEL WEIGHT (Grams)				
38	57.3	58.2	54.8	56.5	56.1	56.6	56.6
30	63.5	59.3	58.1	60.3	55.7	59.4	59.4
20	60.8	59.1	59.8	55.3	57.1	58.4	58.4
15	54.3	52.9	50.8	53.7	48.7	52.1	52.1
Average	59.0	57.4	55.9	56.5	54.4	56.6	56.6
			TOTAL KERNELS PER EAR				
38	633.5	597.0	559.0	522.5	527.0	567.8	567.8
30	664.0	617.5	582.5	580.0	524.5	593.7	593.7
20	624.5	641.5	603.0	559.0	561.5	597.9	597.9
15	611.0	531.5	551.0	551.0	517.5	552.4	552.4
Average	633.3	596.9	573.9	553.1	532.6	578.0	578.0

Table 5. Continued -

ROW SPACING (Inches)	PLANT POPULATION					Average	ROW SPACING Average
	12,000	16,000	20,000	24,000	28,000		
			SHELLING PERCENTAGE				
38	76.3	76.0	75.5	75.8	76.1	75.9	75.9
30	74.0	75.9	74.0	77.3	73.2	74.9	74.9
20	76.0	77.0	77.1	73.9	74.9	75.8	75.8
15	74.4	73.2	71.5	73.7	74.9	73.5	73.5
Average	75.2	75.5	74.5	75.2	74.8	75.0	75.0

Table 6. Analyses of variance for yield, moisture content, lodging, components of yield, and days to 60% silked.

SOURCE OF VARIANCE	d.f.	MEAN SQUARE		
		Yield bu./acre	Moisture content %	Lodging %
Replications	3	1,939.6	21.1	106.0
Row Spacing (R)	3	7,675.8**	91.6**	185.0*
Error (a)	9	942.0	5.0	37.6
Hybrids (H)	1	6,053.2*	370.9**	543.2*
RxH	3	2,265.1	6.4	6.4
Error (b)	12	777.7	10.5	106.2
Plant Populations(P)	4	9,678.6**	0.3	4.7
RxP	12	655.9*	6.7	27.2
PxH	4	450.8	2.5	4.5
RxPxH	12	200.9	5.6	17.6
Error (c)	96	313.8	7.3	36.8
Total	159			

* Significant at 5% level of probability
** Significant at 1% level of probability

Table 6. Continued -- Analyses of variance for leaf area portion and days to 50% silked.

SOURCE OF VARIANCE	d.f.	MEAN SQUARE: Leaf Area Portion: 50 days after planting	60 days after planting	At silking	Days to 50% Silked
Replications	3	29,815.3	98,082.7	48,990.1	32.1
Row Spacings (R)	3	20,012.1*	37,550.6	135,063.7**	35.0**
Error (a)	9	5,295.2	17,027.6	8,409.5	3.9
Hybrids (H)	1	11,880.1	8,151.0	36,890.4	291.6**
RxH	3	5,922.8	10,774.2	12,488.8	3.8
Error (b)	12	5,187.9	13,826.7	9,923.9	8.5
Plant Populations (P)	4	504.3	1,901.2	2,722.8	1.5
RxP	12	1,864.8	3,999.3	2,474.6	1.0
PxH	4	857.6	2,409.4	1,840.6	1.5
RxPxH	12	1,608.2	2,218.4	1,512.9	1.8
Error (c)	96	1,232.7	2,976.0	1,714.4	1.5
Total	159				

* Significant at 5% level of probability
** Significant at 1% level of probability

Table 6. Continued -- Analyses of variance for components of yield

SOURCE OF VARIANCE		MEAN SQUARE							
	d.f.	No. of Kernel Rows	No. of Kernels Per Row	Total Kernels Per Ear	Ear Length	Ear Weight	Shelled Grain Weight	200-Kernel Weight	Shelling %
Replications	3	0.3	86.9	21,726.4	15.6	11,501.9	1,132.1	373.6	10.9
Row Spacings (R)	3	0.5	56.8	18,732.6	13.2	12,155.5*	9,999.1	421.7*	48.8
Error (a)	9	0.9	23.2	5,475.1	3.9	3,154.8	4,127.6	65.4	14.6
Hybrids (H)	1	4.7**	162.2*	78,925.5**	39.4*	19,602.8*	18,818.2	11.9	288.9*
RxH	3	0.6	40.4	6,837.9	6.3	1,699.1	3,548.6	27.3	27.4
Error (b)	12	0.5	28.1	8,174.6	5.9	3,485.6	5,172.8	61.2	15.0
Plant Populations(P)	4	0.2	199.7**	48,781.4**	36.9**	13,235.3**	11,328.9*	92.8*	4.7
RxP	12	0.7	13.1	3,828.5	1.0	552.1	3,654.0	22.3	15.9
PxH	4	0.3	7.0	1,132.9	0.7	533.1	2,916.1	16.8	20.3
RxPxH	12	0.7	12.3	4,858.9	2.6	1,837.9	3,752.9	44.1	24.3
Error (c)	96	0.6	12.6	3,719.0	2.2	1,195.6	4,521.1	28.4	19.4
Total	159								

* Significant at 5% level of probability
** Significant at 1% level of probability

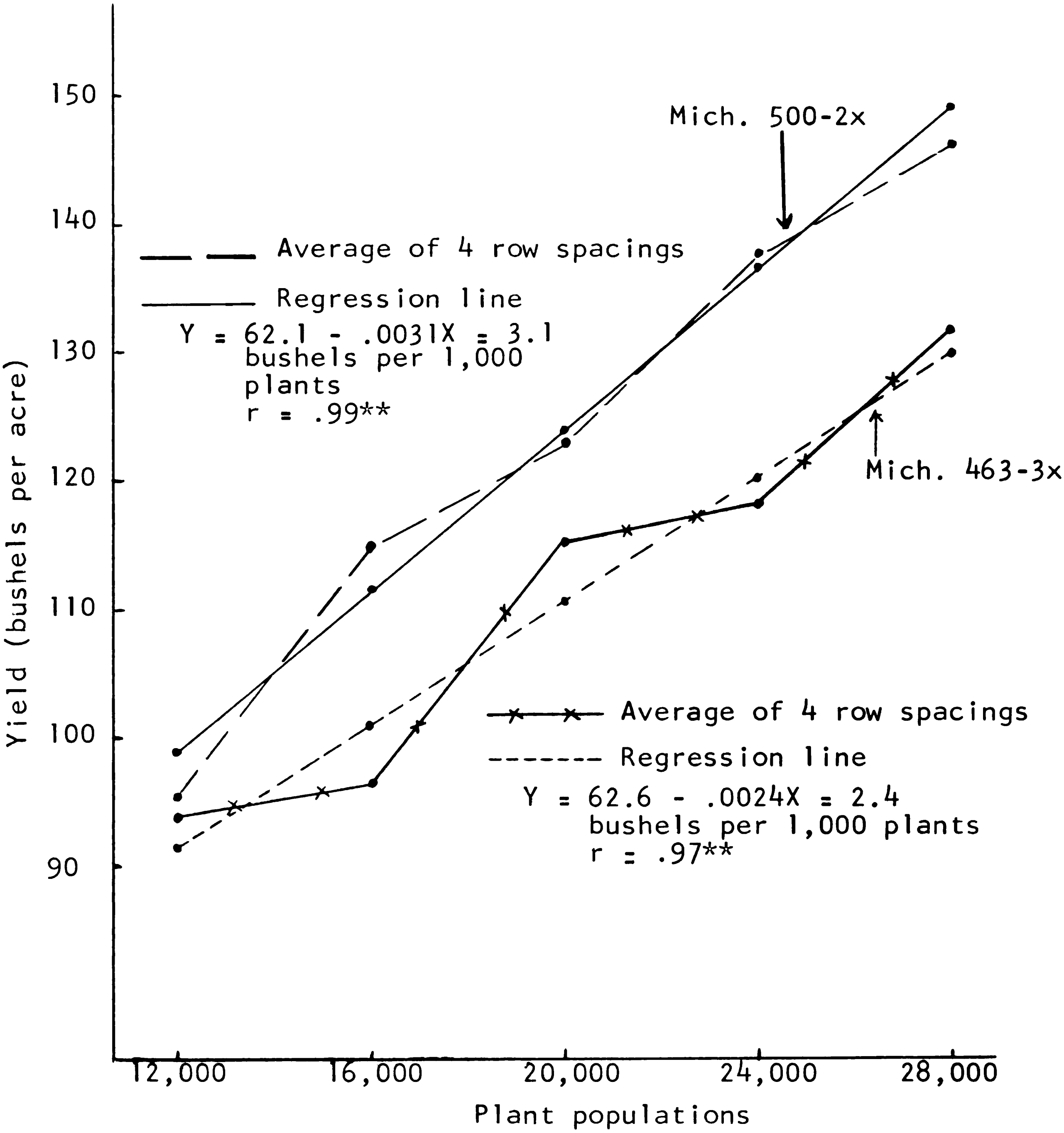

Figure 6. Relationship between responses of two corn hybrids and five plant populations

kernels per row, total kernels per ear, ear length, and ear weight were all significantly higher for Michigan 500-2x which was consistently higher yielding. Shelled weight per ear was 11.6 grams higher for 500-2x but the difference was not significant. Kernel weight differences were not significant.

Plant population significantly affected six of the eight components -- number of kernels per row, total kernels per ear, ear length, ear weight, shelled weight per ear, and kernel weight. These six components all decreased with increasing plant populations. Number of kernel rows and shelling percent were not significantly affected.

Row spacing effects were significant for only two of the eight components -- ear weight and kernel weight.

None of the interactions for any of the yield components was significant, indicating that the effects of hybrids, populations, and row spacings tended to be consistent.

Ear weight was the only component affected significantly by all main effects -- hybrids, plant population, and row spacing. The highest yield, 175.6 bushels, was obtained with an average ear weight of 0.463 pound, Table 3. Ear weight decreased with increasing plant population, averaging .532, .489, .470, .438, and .418 pound for the five populations. Decreases in ear weight averaged 8, 4, 7, and 5% for increases of 33-1/3, 25, 20, and 16-2/3% in plant populations, 12 to 16 to 20 to 24 to 28,000 plants. As population increased, the additional plants per acre more than compensated for the decrease in ear weight.

Ear weights in the two higher yielding row spacings, 30 and 20 inches, were greater, .500 and .503 pound compared to .452 and .424 for the two lower yielding row spacings, 38 and 15 inches.

Correlations of eight components with yield, Table 7, were significant and positive for five components: kernels per row (.21), total kernels per ear (.21), ear length (.18), ear weight (.28), and kernel weight (.32). The multiple correlation of yield with components was 0.41 and significant. While significant, the relationships are small and do not account for a major portion of the yield variations. These correlations of components with yield were noticeably different in size and direction from those reported by Leng (18) for a group of 48 hybrids, Table 8.

Average correlations, Table 7, among yield components were highest for kernels per row, total kernels per ear, ear length, ear weight, and kernel weight and lowest for number of kernel rows, shelled weight per ear, shelling percent, and yield.

Table 7. Simple correlations between yield and its components and between components.

	r Values								
	No. of Kernel Rows	Kernels Per Row	Total Kernels Per Ear	Ear Length	Ear Weight	Shelled Weight	200-Kernel Weight	Shelling %	YIELD
Number of kernel rows	--	.10	.42**	.17*	.23**	.11	-.02	-.03	.09
Kernels per row	.10	--	.94**	.94**	.90**	.34**	.71**	.18*	.21**
Total kernels per ear	.42**	.94**	--	.91**	.90**	.35**	.63**	.15**	.21**
Ear Length	.17*	.94**	.91**	--	.95**	.37**	.69**	.01	.18*
Ear Weight	.23**	.90**	.90**	.95**	--	.40**	.77**	.00	.28**
Shelled Weight	.11	.34**	.35**	.37**	.40**	--	.31**	-.05	.06
200-kernel weight	-.02	.71**	.63**	.69**	.77**	.31**	--	.37**	.32**
Shelled %	-.03	.18*	.15*	.01	.00	-.05	.37**	--	.08
Yield	.09	.21**	.21**	.18*	.28**	.06	.32**	.08	--

* Significant at 5% level of probability ** Significant at 1% level of probability

MULTIPLE CORRELATIONS BETWEEN YIELD AND ITS COMPONENTS

R^2 = 0.17 (Proportion of variability explained by model)

R = 0.41 Multiple correlation coefficient

	Partial correlation coefficients
Number of kernel rows	0.06
Kernels per row	0.06
Total kernels per ear	-0.05
Ear Length	-0.22
Ear Weight	0.20
Shelled Weight	-0.08
200-kernel Weight	0.11
Shelling %	-0.02

Table 7. Continued -

ANALYSIS OF VARIANCE FOR ALL REGRESSION

Source of Variance	d.f.	Mean Square	F
Regression (about mean)	8	2,963.0	3.83**
Error	151	773.0	
Total (about mean)	159		

** Significant at 1% level of responsibility

Table 8. Comparisons of correlations of yield components and correlation between component obtained by Leng (17) with those obtained in this study.

Correlation	Reported by Leng(17)	Obtained in the present study
Yield: kernel weight	.084	.32**
Yield: kernel number	.074	.21**
Yield: raw number	-.361**	.09
Yield: kernels per row	.350	.21**
Kernels per row: row number	-.628**	.10
Kernels per row: kernel weight	-.196	.71**
Row number: kernel weight	-.545**	-.02
Kernel number: kernel weight	-.734**	.63*

* Significant at 5% level of probability

** Significant at 1% level of probability

Leaf Area Portion (LAP). Differences in leaf area measurements were small and not significant for hybrids and plant populations, Tables 4 and 6. The only significant differences were among row spacings in measurements made 50 days after planting and again at silking. The two higher yielding spacings, 30- and 20-inch rows, had higher LAP values than the two lower yielding spacings, 38- and 15-inch rows. Correlation coefficients of LAP with yield were 0.38**, 0.39**, and 0.50** for 50 days after planting, 60 days after planting, and at silking, respectively. There was no indication that LAP on a per plant basis declined with increased population. Consequently, total leaf area per acre increased with population.

Light. Plant population significantly affected light readings in eight out of elevent readings, Table 10. Light readings within the crop canopy decreased with increased plant populations, suggesting that the amount of radiant energy absorbed by the leaf canopy increased with increased plant population, Table 9. Light interceptions averaged 2400, 2640, 2800, 3050, and 3100 foot candles for the five plant populations, 12, 16, 20, 24, and 28,000, respectively.

Differences due to row spacing were significant for only one of the 11 readings. In 20-inch rows, light interception averaged 2-14% more than in 30-inch rows and 6-24% more than

Table 9. Mean plant heights and light interceptions for two corn hybrids grown at five plant populations and four row spacings.

ROW SPACINGS (Inches)	MICHIGAN 500 - 2X Plant Population						MICHIGAN 463 - 3X Plant Population						ROW SPACING Average
	12,000	16,000	20,000	24,000	28,000	Ave.	12,000	16,000	20,000	24,000	28,000	Ave.	
PLANT HEIGHT (inches)													
38	65.5	66.5	65.5	71.5	68.0	67.4	78.0	82.0	78.5	79.0	78.5	79.2	73.3
30	86.5	85.5	81.5	79.0	83.0	83.1	84.5	86.5	82.0	86.0	86.5	85.1	84.1
20	84.0	82.0	83.5	85.5	81.5	83.3	92.0	85.0	89.0	77.0	89.5	86.5	84.9
15	68.0	72.9	57.0	60.5	69.0	65.3	73.5	78.0	74.0	70.0	73.5	73.8	69.6
Average	76.0	76.5	71.9	74.1	75.4	74.8	82.0	82.9	80.9	78.0	82.0	81.2	78.0
LIGHT INTERCEPTION (Hundred foot candles) July 5 - 8AM													
38	12.0	17.5	17.5	17.0	18.5	16.5	16.0	15.0	19.0	18.5	20.5	17.8	17.2
30	15.0	14.0	18.0	21.0	21.0	17.8	13.5	18.5	20.0	19.5	20.5	18.4	18.1
20	16.0	19.0	20.5	21.0	20.0	19.3	17.0	18.5	19.5	19.5	17.0	18.3	18.8
15	12.0	14.0	10.5	14.5	16.0	13.4	10.0	14.5	13.5	17.0	17.0	14.4	13.9
Average	13.8	16.1	16.6	18.4	18.9	16.8	14.1	16.6	18.0	18.6	18.8	17.2	17.0
LIGHT INTERCEPTION (Hundred foot candles) July 5 - Noon													
38	12.5	19.0	19.0	18.0	22.5	18.2	16.5	17.5	19.5	21.0	24.0	19.7	19.0
30	27.0	21.0	22.0	24.0	29.5	24.7	14.0	18.0	19.0	29.0	23.0	20.6	22.7
20	21.5	22.0	22.0	23.0	22.0	22.1	20.0	24.0	21.0	23.5	26.0	22.9	22.5
15	14.0	15.0	12.5	15.5	19.0	15.2	11.5	15.5	15.5	19.5	23.0	17.0	16.1
Average	18.8	19.3	18.9	20.1	23.3	20.1	15.5	18.8	18.8	23.3	24.0	20.1	20.1

Table 9. Continued -

ROW SPACINGS (Inches)	MICHIGAN 500 - 2X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	MICHIGAN 463 - 3X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	ROW SPACING Average
LIGHT INTERCEPTION (Hundred foot candles) July 5 - 4PM													
38	11.5	16.0	16.0	18.5	19.0	16.2	14.0	12.0	16.5	16.5	17.5	15.3	15.8
30	16.5	16.5	14.5	18.0	19.0	16.9	15.5	13.0	18.5	16.5	13.5	15.4	16.2
20	12.5	12.0	15.0	16.0	15.0	14.1	12.0	16.5	13.5	14.0	16.5	14.5	14.3
15	14.5	15.0	14.5	14.0	17.5	15.1	16.5	14.0	17.5	21.0	20.0	17.8	16.5
Average	13.8	14.9	15.0	16.6	17.6	15.6	14.5	13.9	16.5	17.0	16.9	15.8	15.7
LIGHT INTERCEPTION (Hundred foot candles) July 12 - 8AM													
38	8.5	16.0	15.0	14.0	18.0	14.3	15.0	14.0	25.5	19.0	18.0	18.3	16.3
30	35.0	30.0	30.0	30.0	37.0	32.4	21.0	24.0	27.0	44.0	34.0	30.0	31.2
20	24.0	34.0	28.0	31.5	29.0	31.3	28.5	39.0	42.0	44.0	30.0	36.7	34.0
15	9.0	11.0	9.5	13.5	14.0	29.4	14.0	13.5	17.0	15.5	18.0	15.6	22.5
Average	19.1	22.8	23.1	22.3	24.5	26.9	19.6	22.6	27.9	30.6	25.0	25.2	26.0
LIGHT INTERCEPTION (Hundred foot candles) July 12 - Noon													
38	48.0	62.0	63.0	60.0	59.5	58.5	59.0	46.0	70.0	57.9	60.0	58.4	58.5
30	32.5	48.0	52.0	58.0	48.0	47.7	42.5	40.0	49.0	61.0	52.5	49.0	48.4
20	42.0	50.0	63.0	56.0	50.0	52.2	39.0	58.0	42.0	60.0	52.0	50.2	51.2
15	37.0	42.0	32.0	39.0	40.0	38.0	29.0	30.0	45.0	50.0	46.0	40.0	39.0
Average	39.9	50.5	52.5	53.3	49.4	49.1	42.4	43.5	51.5	57.0	52.6	49.4	49.3

Table 9. Continued

ROW SPACINGS (Inches)	MICHIGAN 500 - 2X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	MICHIGAN 463 - 3X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	ROW SPACING Average
			LIGHT INTERCEPTION (Hundred foot candles) July 12 - 4PM										
38	40.0	70.0	52.0	79.0	69.0	62.0	69.0	67.0	67.0	55.0	75.0	66.6	64.3
30	41.5	38.0	42.0	46.0	39.0	41.3	30.0	37.5	48.0	37.0	37.5	38.0	39.7
20	41.0	38.0	48.0	58.0	51.0	67.2	48.0	36.0	49.0	26.0	35.0	38.8	53.0
15	36.0	39.0	39.0	29.0	42.5	55.1	42.0	27.0	41.0	45.0	47.0	40.4	47.8
Average	39.6	48.8	45.3	53.0	50.4	56.4	47.3	41.9	51.3	40.8	48.6	46.0	51.2
			LIGHT INTERCEPTION (Hundred Foot candles) July 20 - 8AM										
38	8.0	15.5	18.0	19.0	21.0	16.3	21.5	18.0	25.0	19.0	25.0	39.7	28.0
30	20.5	18.0	23.0	20.0	30.5	22.4	17.0	17.0	25.0	27.0	33.5	23.9	23.2
20	18.5	23.5	26.0	30.5	23.0	24.3	18.5	15.0	19.0	27.5	24.0	20.8	22.6
15	10.5	16.0	16.5	13.0	23.0	15.8	16.0	16.5	15.0	18.5	18.5	16.9	16.4
Average	14.4	18.3	20.9	20.6	24.4	19.7	18.3	16.6	21.0	23.0	25.3	25.3	22.5
			LIGHT INTERCEPTION (Hundred foot candles) July 20 - Noon										
38	29.5	36.0	28.0	44.0	33.5	36.2	21.5	23.5	23.5	26.0	23.5	23.6	29.9
30	21.0	21.0	29.0	27.5	36.0	26.9	24.0	25.0	22.0	35.5	43.5	30.0	28.5
20	22.5	28.0	31.5	37.5	31.0	30.1	22.5	28.5	35.5	30.5	37.0	30.8	30.5
15	23.0	26.0	23.5	39.0	51.5	32.6	15.5	24.5	26.0	24.5	28.5	23.8	28.2
Average	24.0	27.8	30.5	37.0	38.0	31.5	20.9	25.4	26.8	29.1	33.1	27.1	29.3

Table 9. Continued

ROW SPACINGS (Inches)	MICHIGAN 500 - 2X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	MICHIGAN 463 - 3X Plant Population 12,000	16,000	20,000	24,000	28,000	Ave.	ROW SPACING Average
LIGHT INTERCEPTION (Hundred foot candles) July 26 - 8AM													
38	19.5	20.5	21.0	25.0	21.5	21.5	28.5	29.0	26.5	29.5	33.5	29.4	25.5
30	27.0	20.5	34.5	33.5	39.0	30.9	26.0	30.5	23.0	34.0	28.0	28.3	29.6
20	27.0	30.0	28.5	30.0	27.0	28.5	33.0	46.0	29.0	32.0	44.0	38.8	33.7
15	18.0	25.0	16.0	19.5	26.5	21.0	26.0	35.5	25.0	26.5	29.0	26.4	23.7
Average	22.9	24.0	25.0	27.0	28.5	25.5	28.4	32.8	28.4	30.5	33.6	30.7	28.1
LIGHT INTERCEPTION (Hundred foot candles) July 26 - Noon													
38	32.5	29.0	29.0	32.0	36.5	31.8	32.0	29.0	30.0	34.0	31.0	31.2	31.5
30	37.0	22.0	34.0	39.0	41.0	34.6	28.0	24.0	26.0	34.0	26.0	27.6	31.1
20	31.5	36.0	45.0	47.0	42.0	40.3	28.0	38.0	27.0	38.0	35.0	33.2	36.8
15	31.5	28.0	30.0	26.0	49.0	32.9	28.0	22.5	32.0	32.0	35.0	29.9	31.4
Average	33.1	28.8	34.5	36.0	42.1	34.9	29.0	28.4	28.8	34.5	31.8	30.5	32.7
LIGHT INTERCEPTION (Hundred foot candles) July 26 - 4PM													
38	22.0	27.0	23.0	29.5	27.0	25.7	31.0	26.0	28.0	40.0	23.5	29.7	27.7
30	21.0	21.0	31.0	37.0	37.5	29.5	17.5	19.0	19.0	31.0	22.0	21.7	25.6
20	29.0	20.0	36.0	34.0	30.5	31.9	22.5	22.5	25.0	25.5	25.5	24.2	28.1
15	23.0	24.0	26.0	22.0	30.0	25.0	23.5	23.5	26.5	27.0	25.5	25.2	25.1
Average	23.8	25.5	29.0	30.6	31.3	28.0	23.6	22.8	24.6	30.9	24.1	25.2	26.6

Table 10. Analyses of variance for plant height and light interception at four stages of growth.

SOURCE OF VARIANCE	d.f.	MEAN SQUARE			
		Plant height (inches)	Light interception (hundred foot candles)		
			July 5		
			8 AM	Noon	4 PM
Replications	1	1,102.6	177.0	57.8	66.6
Row Spacings (R)	3	1,188.7	93.9	197.2	18.1
Error (a)	3	580.1	39.0	81.0	7.6
Hybrid (H)	1	812.8	4.5	0.0	7.6
RxH	3	105.3	5.2	38.2	17.3
Error (b)	4	154.9	33.7	195.0	97.2
Plant Populations (P)	4	42.8	61.6*	106.6**	31.5*
RxP	12	25.3	6.1	9.7	3.9
PxH	4	13.3	1.2	21.2	4.4
RxPxH	12	26.8	5.7	13.0	9.9
Error (c)	32	20.8	9.2	26.1	9.1
Total	79				

* Significant at 5% level of probability

** Significant at 1% level of probability

Table 10. Continued -

SOURCE OF VARIANCE	d.f.	MEAN SQUARE				
		Light interception (Hundred foot candles)				
		JULY 13			JULY 30	
		8 AM	Noon	4 PM	8 AM	Noon
Replications	1	1,428.0	594.1	1,394.4	1.0	22.1
Row Spacings (R)	3	2,140.9*	1,295.4	2,866.3	203.1	24.0
Error (a)	3	239.8	309.3	823.3	97.0	336.0
Hybrid (H)	1	156.8*	1.8	42.1	25.3	387.2
RxH	3	62.0	15.6	237.8	66.3	281.4
Error (b)	4	14.9	236.3	437.7	55.8	237.2
Plant Populations (P)	4	126.2*	464.9*	91.4	188.6**	433.6**
RxP	12	50.5	59.0	89.3	28.9	60.1
PxH	4	54.0	80.4	284.0**	17.8	18.5
RxPxH	12	32.9	111.3	165.1*	20.7	54.1
Error (c)	32	37.8	131.7	68.0	29.6	46.0
Total	79					

* Significant at 5% level of probability

** Significant at 1% level of probability

Table 10. Continued

SOURCE OF VARIANCE	d.f.	MEAN SQUARE Light interception (Hundred foot candles) JULY 26 8 AM	Noon	4 PM
Replications	1	551.3	987.0	86.1
Row Spacings (R)	3	396.2	147.3	43.7
Error (a)	3	186.1	157.1	182.3
Hybrid (H)	1	551.3*	391.6	159.6
RxH	3	157.0	50.7	173.7
Error (b)	4	62.8	217.4	34.6
Plant Populations (P)	4	69.6	181.7	132.2**
RxP	12	26.0	61.6	40.8
PxH	4	18.9	62.2	37.6
RxPxH	12	41.7	32.5	16.4
Error (c)	32	40.4	71.0	32.9
Total	79			

* Significant at 5% level of probability
** Significant at 1% level of probability

in 38-inch row for six of the 11 readings, Table 9. While there was some indication of more light interception by narrow rows, the differences were not consistent and large enough to be significant.

More light interception by the leaf canopy in narrow rows was expected. Since the readings below the leaf canopy were made about 7 inches from the row for all row spacings, the readings would tend to be more similar than if they had been taken more nearly in the center of the inter-row space. Photographs of leaf shadows, Figures A and B, show much less light reaching the soil surface in narrow rows.

Only two of the 11 readings were significantly different for the two hybrids. Average light interceptions for the 11 measurements over all population and row combinations were 2,950 foot candles for Michigan 500-2x and 2,810 foot candles for Michigan 463-3x. The two hybrids differed by only 6.4 inches, on the average in plant height.

Maturity. The two hybrids differed significantly in days to 50% silking and in moisture content of ears at harvest, Table 6. Michigan 500-2x averaged 3 days later in silking and 3% higher moisture content at harvest.

Differences in silking and moisture content due to plant population were not significant. Silking was delayed two days in 15-inch rows. Moisture content of ears harvested

A

Distribution of shaded and unshaded areas for 38-inch E-W row, noon, July 27. 24,000 plants/acre.

Distribution of shaded and unshaded areas for 30-inch E-W row, noon, July 27. 24,000 plants/acre.

B

Distribution of shaded and unshaded areas for
20-inch E-W row, noon, July 27. 24,000 plants/acre.

Distribution of shaded and unshaded areas for
15-inch E-W row, noon, July 27. 24,000 plants/ acre.

from 15-inch rows was significantly higher, about 3 percent, than for the other row spacings. Delayed maturity in the 15-inch rows reflects the effect of tractor wheel soil compaction at planting resulting in delayed seedling emergence.

Lodging. Michigan 463-3x had significantly more lodging (stalk breakage below the ear) at harvest than Michigan 500-2x, 5.8% compared to 1.9%. Lodging was not significantly affected by plant population. The plots were harvested early, September 30, and later harvest might have presented a different picture on lodging. There were no significant differences in the amount of lodging among comparisons of 38, 30, and 20-inch rows. Lodging was significantly higher in the 15-inch rows, again reflecting possible adverse effects of tractor wheel compaction of the soil at planting time.

DISCUSSION

Some corn growers, corn breeders, and others believe that short hybrids will yield more than taller hybrids particularly at high plant populations and with narrow rows. Less mutual leaf shading and consequently a higher net photosynthetic efficiency is postulated for short hybrid. Critical evaluation of short versus tall hybrids for corn production requires the use of relatively isogenic short and tall hybrids. Comparisons made with non-isogenic short and tall hybrids are confounded with differences in genotype.

Leng (17) found that brachytic 2 hybrids were lower in yield than their normal tall counterparts. Brachytic 2 is a recessive gene in corn that results in shorter internodes, particularly the lower internodes. Relatively isogenic inbreds and subsequently hybrids of br 2 and Br 2 can be developed from backcross breeding programs.

Pendleton and Seif (22) studied a brachytic 2 dwarf hybrid, Illidwarf 513, at six populations (12 to 32,000) and three row spacings, 20, 30, and 40-inch rows. A normal height hybrids was not included in the study. Yields increased as population increased from 12 to 20,000 and then decreased as population increased to 32,000. Highest yield, 107.7 bushels, was obtained with 20,000 plants per acre in 30-inch rows.

Yields were consistently lower in 20 than in 30-inch rows.

They concludes that "the yields of brachytic 2 dwarf corn were not raised by increasing the plant population much above what is now recommended for normal height corn in the Corn Belt."

In another study, Pendleton and Seif (23) compared Illinois 513, a brachytic 2 dwarf version of U.S. 13, with normal U.S. 13 in 40-inch rows with 16,000 plants per acre. The dwarf plants averaged 72 inches in height, yielding 63.5 bushels per acre, and the normal plants averaged 106 inches, yielding 91.1 bushels. The dwarf hybrid yielded 44% less than the tall hybrid.

Using another recessive dwarfing gene, compact, Nelson and Ohlrogge (20, 21) reported that the compact inbred Hy and compact hybrids possessed unusual tolerance to high population. Compact hybrids at a 42,000 population yielded as high as 163 bushels per acre while a normal (not isogenic) hybrids yielded only 15 bushels per acre at the same population. The normal hybrids was not grown at a lower and possibly more favorable population. Lodging was very high in most of the compact hybrids.

Sowell et al. (31) explained the unusual grain producing ability of compact inbred Hy at high population as follows. Compact plants completed vegetative growth before flowering whereas normal plants made more vegetative growth during flowering than at any other stage of development. Since vegetative growth of compact plants ceased before flowering, more photosynthates were available for ear shoot initiation and development. Only 5 percent of compact plants failed to produce grain at a population of 52,000 compared to grain failure on 62 percent of the normal inbred Hy plants.

These comparisons (17, 20, 21, 22, 23) of dwarf (brachytic and compact) with normal height isogenic hybrids did not involve critical population x row spacing experiments. The isogenic level of materials was not as high as desirable for this type of comparison.

The present investigation involved two hybrids that were 50% related in genotype, Michigan 500-2x (W64A x oH 43) and Michigan 463-3x [(Oh51AxMS67)xW64A]. Previous observations of plant height for the two hybrids indicated a difference of about 18 inches. However, the average difference in plant height for this experiment was only 6.4 inches and it was not significant. Larger differences in plant height are necessary for experiments to determine the effects of plant height on corn production.

The shorter hybrid, Michigan 500-2x, consistently yielded more than Michigan 463-3x but the yield differences did not appear to be related to plant height. More favorable yield component factors for Michigan 500-2x appeared to be more important in accounting for its yield superiority.

To date, there is no clear evidence that short hybrids are necessarily superior to taller hybrids.

Efficiency of water use and the amount of net radiation intercepted by leaves (2, 7, 36, 37) indicate that corn spaced more nearly equidistant in narrow rows could yield more than corn in conventional spacing.

Yields averaged 24.2 and 30.8% more in 30- and 20-inch rows, respectively, than in 38-inch rows in this current study. Lower yields in 15-inch rows than 30- or 20-inch rows appeared to be due to soil compaction by tractor wheels at planting. Emergence was delayed, early seedling vigor was reduced, stands were more erratic, plants were smaller and less productive in the 15-inch rows. These effects illustrate one of the practical difficulties for unusually narrow rows. Tractors with very narrow tires appear to be essential for row spacings of 15 inches or less.

Yield differences in favor of 30- and 20-inch rows were larger than those previously reported in Michigan, 5% and 14% (29). Yield levels in this experiment were higher than those of the previous experiments. A yield difference of 93% (161 bushels compared to 83 bushels) in favor of 20-inch rows compared to 40-inch rows was obtained with irrigated corn in Nebraska (6, 10).

The range in yields from 84.7 to 175.6 bushels per acre (more than doubled) depended upon the specific combination of hybrid, plant population, and row spacing. The difference, 90.9 bushels, illustrates the importance of these factors in corn production. The highest yield occurred with Michigan 500-2x at a population of 28,000 in 20-inch rows. Costs of production (primarily seed cost) related to the choice of the best hybrid and plant population for maximum yield are relatively minor. Production costs (more expensive machinery and added herbicides) for narrow row culture will be higher than for more conventional 36- to 42-inch rows.

The same relatively high level of fertilizer, 206-112-112 pounds of N-P_2O_5-K_2O per acre, was used for all treatments. The highest recorded corn yield in the United States, 304.6 bushels per acre, was produced in Mississippi in 1955 using a total fertilizer program of 303-140-140 and a population of 25,000 (25). Irrigation was available but was not needed.

While additional fertilizer might haveincreased yields further, it appears available moisture was more likely the limiting factor. June, July, August rainfall (11.19 inches) was 2.22 inches above the normal 8.97 inches. Rainfall during 29 days, July 20 to August 18, was only 0.87 inches occurring as five showers of 0.02 to 0.31 inches. This period included the most critical stages of plant development, tassel and silk development, pollination, and early ear and grain development. During these stages of growth, corn uses moisture at a rate of 0.25 inches per day (15). Soil moisture reserves from more adequate rainfall earlier, 5.23 inches from June 17-July 19, and 2.89 inches in late August reduced the adverse effects of the moisture deficient 29 day period. Michigan is the driest state east of the Mississippi River for average June, July, August rainfall (1).

In most population x row spacing experiments (29) including this one, population had a greater total effect on yield than row spacing. Yield increases due to increasing plant population were greater in narrow (30- and 20-inch) rows than in 38-inch rows. When conditions are favorable for high yields in narrow rows, significant interactions of population x row spacing in this study and in others (29) illustrate than an optimum plant population may be relatively more important in narrow row corn production than in conventional row culture.

Hybrid interactions with population and with row spacing were not significant. This, too, is in general agreement with published results of other experiments (29). Only two hybrids were involved here.

Several states (11, 13, 30) evluated large numbers of hybrids for response to plant population. Rossman (27, 28) found that correlations for yields at two populations for 30-64 hybrids in a number of tests conducted in Michigan, Iowa, and Virginia ranged from 0.592 to .986, all highly significant. The correlations tended to be higher at high yield levels. Significant correlations for hybrids tested at two or more plant populations indicated that most of the highest yielding hybrids at the lower population were also among the highest yielding hybrids at a higher population. Since there were some exceptions, continued testing of hybrids at two or more plant populations is warranted. Some hybrids gave a larger percentage increase at the higher population than others. From the data obtained from 45 comparisons of large groups of commercial hybrids at two plant populations during three years, 1964-66, in Iowa, Hillson and Hutchcroft (13) state, "The data indicate that relatively few varieties tested are better adapted at high plant populations than at normal." Interaction of cultural, climatic, and genetic factors influencing yields requires extensive testing of corn hybrids in order to identify, with reasonable certainty, their genetic potential to increase yield at high populations.

While a relatively large number of hybrid x population comparisons have been made, no published information is available for large groups of hybrids in hybrid x row spacing experiments. In this study with only two hybrids, the interactions of hybrids x population and hybrids x row spacing were similar in relative magnitude and neither was significant. Since there is a popular conception that some hybrids do respond more than others in narrow rows, experiments with larger groups of hybrids in various row spacings are needed.

Correlations of yield with components of yield were small but significant in most cases. Component compensation, an increase in one component being accompanied by a decrease in another component, would appear to keep correlations relatively small. Correlations were generally positive in contrast to more negative correlations obtained by Leng (18) from a different type of study involving 48 hybrids.

Plant population significantly affected six of the eight yield components while row spacing affected only two of the components. Components, except for number of kernel rows and shelling percent, tended to decrease with increasing population. Components tended to be greater for narrow rows, except 15-inch rows due to soil compaction.

Colville (4) found that ear weight, ear length, ear diameter, weight per 100 kernels, and ears per 100 plants decreased linearly and correlated statistically with population. None of these factors correlated with yield because of the curvilinear response of yield to population. Number of ears per 100 plants was one of the largest contributing factors to yield response.

Determinations of ears per plant and percent barren plants were not made in this experiment.

Narrow rows provide more nearly equal area around each plant at the same population. Equidistance per plant should permit relatively more absorption of radiant energy by the more uniformly distributed leaves.

Aubertin and Peters (2) compared energy absorbed by corn plants of 20- and 40-inch rows at populations of 15,600 and 31,300. Plants in 20-inch rows absorbed 3.1 times and 13.1 times more net radiation than those in 40-inch rows at 15,600 and 31,300 population, respectively. Others (7, 33, 35, 37) have also reported more net radiation available in narrow rows.

As expected, more light was intercepted at the high populations. Twenty-five percent more light was intercepted by 24,000 plants per acre than by 12,000. The increase in light interception was neither proportional to the increase in population nor to the increase in yield with increased population. Higher yields at increased populations were not due entirely to increased light interception within the leaf canopy.

Light measurements did not show a consistent and significant difference in favor of narrow rows. The below-canopy readings were made about 7 inches from the row in all spacings.

Readings made near the center of the inter-row space would have been more appropriate. Photographs of leaf shadows on the soil surface indicated more shading of the soil and more light interception within narrow rows.

Leaf area portion (LAP) was significantly correlated in a postive direction with yields. Differences among hybrids and plant populations were not significant. LAP values were higher for the narrow rows with higher yields. Since LAP values per plant did not change significantly with increasing population, it appeared that total leaf area per acre did increase with population.

Stickler (32) found that LAP per plant was highly associated with grain yield per plant but was not significantly influenced by row spacing. Combined leaf area per plant for three leaves (primary ear leaf with the first leaf above and below) decreased from 357 square inches at 16,000 to 334 square inches at 24,000 populations.

Eisele (10) reported that leaf area per plant was 30 percent less for five plant hills than for one plant hill. Total leaf area would be 3-1/2 times greater with five plants in a hill. Eik and Hanway (9) found that yield was linearly related to leaf area index at silking time.

Maturity as measured by days to silking and by moisture content of ears at harvest were not affected by either plant population or row spacing. Reports of delays in silking of one to five days and a wider spread in timing of pollen with silk for pollination at high populations were reviewed by Rossman and Cook (29). Less silking delay with less of a pollination problem and fewer barren plants occurred in experiments that had more optimum soil moisture conditions. The average increase in moisture content of grain was about 0.4 percent for each added 4,000 plants for several experiments reviewed (29).

Lodging (stalk breakage) was not affected by either plant population or row spacing. The plots were harvested early, September 30. Differences in lodging would be more likely to appear with later harvest. Rossman and Cook (29) concluded that lodging generally increased as population increased for the experiments they reviewed. In some reports, more lodging occurred in narrow rows while no difference in lodging was apparent in other reports.

SUMMARY

Two corn hybrids that are 50% related in genotype and differing in plant height (based on previous observations) were used to study the effects of four row spacings and five plant populations on total yield, components of yield, maturity, lodging, leaf area, and light interception. Soil and environmental conditions were conducive to good corn production in 1967.

The average difference in height, 6.4 inches, between the two corn hybrids was not significant. Isogenic hybrids with more of a difference in height are needed to adequately assess the importance of plant height in corn production.

The shorter hybrid, Michigan 500-2x, was higher yielding than the slightly taller hybrid, Michigan 463-3x. Most of the yield components tended to be larger for 500-2x.

Yields ranged from 84.7 to 175.6 bushels per acre depending on the specific combination of hybrid, plant population and row spacing. The highest yield, 175.6 bushels, was obtained with Michigan 500-2x at a population of 28,000 plants per acre in 20-inch rows. Ear weight was 0.463 pound.

Plant population had the greatest effect on yield, row spacing next, and then hybrid. With increasing population, yields increased more in narrow rows (30- and 20-inches)

than in 38-inch rows. Soil compaction by tractor wheels at planting depressed yields in 15-inch rows.

Plant population significantly affected six of eight yield components while row spacing effects were significant for only two of the eight components. Correlations with yield were small but significant for five components: kernels per row (.21), total kernels per ear (.21), ear length (.18), ear weight (.28), and kernel weight (.32). The multiple correlation for yield with all components was 0.41.

Leaf area portion (LAP) was significantly correlated with yield. Differences due to hybrids and populations were small and not significant. LAP on a per plant basis did not decrease with increased population and, consequently, leaf area per acre increased. The two highest yielding spacings, 30- and 20-inch rows, had higher LAP values than the lower yielding spacings, 38- and 15-inch rows.

Light interception increased significantly with population for eight of the 11 readings. Light readings were made 7 inches from the row for all spacings and differences due to row spacings were generally not significant. Photographs of leaf shadows did show a difference. Light readings should have taken in the center of the inter-row space.

Maturity and lodging were not significantly affected by plant population and row spacing.

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