This is to certify that the

thesis entitled

EFFECT OF ROW SPACING, HYBRID SELECTION, POPULATION, AND PLANTING DATE ON CORN (*Zea mays* L.) GRAIN AND SILAGE PRODUCTION IN MICHIGAN

presented by

William D. Widdicombe

has been accepted towards fulfillment
of the requirements for

M.S. degree in Crop and Soil Sciences

Daryl D. Warncke
Major professor

Date 12/13/00

PLACE IN RETURN BOX to remove this checkout from your record.
TO AVOID FINES return on or before date due.
MAY BE RECALLED with earlier due date if requested.

DATE DUE	DATE DUE	DATE DUE
OCT 2 1 2001		
10 23 01		
JUN 1 2 2005		
06 19 05		

EFFECT OF ROW SPACING, HYBRID SELECTION, POPULATION, AND PLANTING DATE ON CORN (*Zea mays L.)* GRAIN AND SILAGE PRODUCTION IN MICHIGAN

By

William D. Widdicombe

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTERS OF SCIENCE

Department of Crop and Soil Sciences

2000

ABSTRACT

EFFECT OF ROW SPACING, HYBRID SELECTION, POPULATION, AND PLANTING DATE ON CORN (*Zea mays L.)* GRAIN AND SILAGE PRODUCTION IN MICHIGAN

By

William D. Widdicombe

In recent years, Michigan corn growers have been interested in producing corn (*Zea mays L.*) in row widths narrower than 30-inches. Corn producers questioned whether hybrid types responded differently to row spacing, population, and planting date. Between 1997 and 1999, narrow row trials covering 15 site-years were conducted across Michigan. The largest yield increase came from an increase in plant population. Corn was planted at population levels of 26K, 30K, 34K, 38K, and 42K plants per acre. On average, grain yield increased one bushel per acre for every additional 918 plants. Planting dates early in May out-yielded later planting dates. In the Central maturity zone in Michigan, 15-inch row spacing out-yielded 30-inch rows by 8.5 bushels per acre when averaged across years. There were significant yield differences between hybrids correlated with maturity. However, there was no interaction of hybrids by row spacing. Grain moisture declined as row width was narrowed. Total plant dry matter production increased as plant population increased. There were inherent differences between hybrids, which affected silage quality. Digestibility of corn silage decreased as population increased. Silage quality was not affected by row spacing. Total plant dry matter increased as row width decreased.

ACKNOWLEDGMENTS

I would like to sincerely thank the members of my graduate committee, Dr. Darryl Warncke, Dr. Chris DiFonzo, Dr. James Kells, and Dr. Kurt Thelen. Special thanks to Dr. Darryl Warncke for serving as my academic advisor.

I would like to thank Dr. Kurt Thelen for serving as my mentor and for his assistance with this thesis. My thanks also go to Keith Dysinger and Sue Canty for their hard work and help in the field. Thanks to The Corn Marketing Program of Michigan whose commitment to research has funded this project.

I would like to extend my heartfelt gratitude to my parents, George and Evelyn, whose faith in God has encouraged and guided me throughout my life. Finally, my profound appreciation and love goes to my wife Melinda for her constant support, patience, and faith in my abilities, which enabled me to complete this project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

EFFECT OF ROW SPACING AND PLANT POPULATION ON HYBRID CORN PERFORMANCE IN MICHIGAN

Abstract

In recent years, Michigan corn growers have been interested in growing corn (*Zea mays L.*) in row widths narrower than 30-inches. Planting corn in narrower rows would allow Michigan farmers who grow soybeans [*Glycine max* (L.) *Merr.*] in 15-inch rows and sugar beets (*Beta vulgaris*) in 22-inch row spacings to better utilize equipment resources. Narrow row research has yielded inconsistent results ranging from 0 % to 7 % yield increase. Researchers have questioned whether the selection of hybrid by plant type was important to increasing yield in narrow row systems. Michigan Sate University conducted a three-year study covering 15 site-years. The objectives of this study were to a) determine the effects of narrow rows on corn production, b) determine the influence of hybrid type on narrow row systems, and c) study the response of narrow row systems to changes in plant populations. Four hybrids with differing plant characteristics were planted at three row spacings of 30-, 22-, and 15-inches. The three row spacings in turn were planted at five plant population levels of 26K, 30K, 34K, 39K, and 42K. Plots were arranged randomly in a split-split plot configuration. Results of this study indicate that as plant population levels increased, yield consistently increased. Narrow rows appear to have a yield advantage over wider rows at the northern locations. Results also showed that well adapted hybrids that yield well in 30-inch row systems also yield well in narrow row systems.

Introduction

In recent years, producers have been interested in producing corn (*Zea mays L.*) in row spacings narrower than 30-inches. Producers, who wish to maximize equipment use between different crops, have driven this trend. Sugar beet growers using 22-inch row spacing for both sugar beets (*Beta vulgaris*) and soybeans [*Glycine max* (L.) *Merr.*] began to ask questions whether corn could also be produced in 22-inch rows. Corn and soybean growers, who plant soybeans with row splitters, also began to question whether corn could be efficiently produced in 15-inch rows. The question of growing corn in narrow rows historically generated much debate about optimal row spacing and population. Researchers looked at these questions over the years and are reassessing the possibilities as corn genetics continue to evolve. In 1908, Hume et al. reported a slight advantage of 33 x 33-inch over 44 x 44-inch spacing of hill plots in northern Illinois at both the two- and three-kernel planting rate. These debates of row spacing and corn population will continue as producers look for ways to optimize their corn production.

Development of more effective herbicides with longer residual activity reduced reliance on cultivation for weed control and eliminated the need for check-row planting which facilitated cross row cultivation. This allowed for the introduction of drilled corn, which changed planting patterns within the row. In Michigan, Rounds et al. (1951) found that in ten plots, drilled corn yielded 7% better than did corn planted in hills. Drilling corn allowed higher plant densities than utilized under previous hill planting systems. Higher plant densities had a greater effect on yield than row width or planting patterns (Rossman et al., 1966). Growing corn in an equidistant planting pattern reduces inter-plant competition, allowing better utilization of nutrients, moisture, and solar radiation. Uniformity between plants within rows also affects yields by increasing bushels per acre (Krall et al., 1997; Nafziger, 1996).

Further advancement in engineering produced harvesting equipment that allows harvesting of ultra narrow rows (15-inch). These new technologies spurred the debate on the interaction of row spacing and plant density. Extensive research in Minnesota (Porter et al., 1997; Westgate et al., 1997), Indiana (Bullock et al., 1988; Nielson , 1988), New York (Cox et al., 1998), Ontario (Scheifele et al., 1996; Murphy et al., 1996), Kansas (Krall et al., 1977), Illinois (Ottman and Welch, 1989), and Ohio (Thomison and Jordan 1995) added to our understanding of the interaction of narrow row spacing and plant population.

Corn grain yield results from narrower row studies are not consistent. Results vary from zero yield advantage of planting corn in narrow rows (Johnson et al., 1998), to a 7% increase in yield over wider rows as reported by Porter et al. (1997). Nielson (1988) reported a 2.7% increase in yield of narrow rows over wider rows across nine Indiana locations. The advantage of narrower rows seems to be in the northern locations where the growing season is short. Paszkiewicz (1997) summarized eighty-four university and industry studies and reported corn grown north of the I-90 corridor responded on average with an 8 % increase in yield than did wider 30-inch rows. Cox et al. (1998) summarizing Paszkiewiez, suggested that corn grown in narrow rows north of the 44°N latitude had a yield advantage over wider rows.

Hybrids developed in the last few years are able to withstand higher plant populations better than older hybrids as reported by Tollenaar (1989). The newer hybrids could withstand populations better because of a decrease in stalk lodging. Also newer hybrids were able to withstand stress better resulting in production of fewer barren plants (Tollenaar, 1991). When selecting hybrids for higher plant densities, Thomison and Jordan (1995) reported that hybrid ear type was of limited importance in determining optimum plant densities. Nafziger (1994) evaluated two hybrids with reportedly different responses to plant density and found no significant hybrid x plant population interaction.

The objectives of this study were to a) determine the effects of row spacing on corn yield, maturity, and lodging in Michigan; b) determine the influence of hybrid type and row spacing on yield response; and c) study the influence of plant population and row spacing on on yield response.

Materials and Methods

Field research was conducted in 1997, 1998, and 1999 throughout Michigan (Table 1.1), resulting in 15 site-years. Trial locations were chosen that best represented the diverse soil types and cultural practices utilized in the state of Michigan. The trials were separated into Southern and Central Zones. Three locations were planted in the Central Zone, in 1997.

Table 1.1: Test locations by year and region.

Region	1997	1998	1999	Zone
Central	*	*	*	Central
Saginaw Valley	*	*	*	Central
Thumb	*	*	*	Central
South East		*	*	Southern
South West[1]		*	*	Southern

[1] Location had both irrigated and non-irrigated trials.

The experiment was designed as a randomized complete block with a split-split plot arrangement with four replications. The hybrid represented the whole plot (110 by 30 feet), row spacing represented the split-plot (110 by 10 feet), and plant population represented the split-split plot (22 by 10 feet). This design was chosen so the interaction between hybrid, row spacing, and plant population could be observed.

To more efficiently plant and harvest these trials, a seven-row, 15-inch corn planter was built in 1997. This planter also adjusted to plant 30- and 22-inch rows. To configure the planter for four 30-inch rows, units 2, 4, and 6 were locked up with their seed drives turned off. The planter toolbar extended to plant five 22-inch rows. Row units 1 and 7 were locked up and turned off, so they would not interfere with adjacent plots. An Accu-plant™ programmable rate control processor was installed on the planter so quick population changes could be made. Tractor wheel spacing was adjusted so wheel tracks did not interfere with planted rows. Two mechanical corn heads were also built to harvest the 15- and 22-inch rows. One conventional three-row, 30-inch corn head was fitted with five 15-inch row units utilizing one gathering chain per unit. The original row units were then mounted on a narrower frame and adjusted to 22 inches.

Four hybrids were selected and planted at three different row spacings of 30-, 22-, and 15-inch rows. Within each row spacing, hybrids were planted at five target populations of 26K, 30K, 34K, 38K, and 42K plants per acre. The middle rows of each plot were harvested for yield to allow one border row on each side of the plot. In the 30-inch rows, only two rows were harvested, while in the 22- and 15-inch plots, three and five rows were harvested, respectively.

To better match the hybrid to each location and zone, hybrids with different maturity dates and agronomic characteristics were chosen. The same hybrids were planted at all locations in 1997. In 1998 and 1999, six different hybrids were selected and matched to the maturity zones. Of these six hybrids, four were selected for each maturity zone. The two earliest hybrids were used in the Central Zone along with the two medium-maturing hybrids. The same medium-maturing hybrids were then used in the Southern Zone along with the two later-maturing hybrids (Table 1.2).

Table 1.2: Hybrid maturity and agronomic characteristics. Hybrids are listed by year utilized and in order of maturity.

1997					
Company	Hybrid	Maturity	Ear Type	Height	Leaf type
Pioneer	PIO 3751	97 day	Flex	Med-tall	Wide
Great Lakes	GL 4929	99 day	Determinate	Short	Semi-upright
Garst	GRST 8735	102 day	Determinate	Med-short	Thin-upright
Garst	GRST 8640	104 day	Flex	Tall	Wide-upright
1998 – 1999					
Company	Hybrid	Maturity	Ear Type	Height	Leaf type
Novartis	Max 86	93 day	Determinate	Tall	Erect
Renk	RK 552	95 day	Indeterminate	Medium	Erect
Great Lakes	GL 4758	100 day	Flex	Med-tall	Semi-upright
Pioneer	PIO 3573	103 day	Flex	Med-short	Semi-upright
Great Lakes	GL 5715	105 day	Determinate	Medium	Wide
Renk	RK 775	108 day	Indeterminate	Medium	Semi-upright

Plant population was determined at all locations after corn emergence. Plots were thinned by hand if plant population exceeded target levels for the plot. Lodging observations were recorded prior to harvest. Plants were considered lodged if corn stalks were broken below the ear. The percent of lodging was calculated based upon the total number of plants per plot.

Plots were harvested mechanically for corn grain. Moisture content and field weights were automatically measured by the GrainGage™, a HarvestData System™ mounted on a plot combine. Grain yields are reported at a standard 15.5 % moisture. Test weights were also recorded and reported at harvest moisture.

All data was analyzed with the analysis of variance (ANOVA) and the Mixed Linear Model in SAS Statistical Software Package version 6.12 (1989-1996 SAS Institute Inc., Cary, NC.,). The Mixed Linear Model is able to calculate the appropriate error terms for tests associated with the split-split plot design. Mean separations between all variables were obtained by Tukey's Least Significant Difference Test. To control experimental error, data was blocked by location (Kuehl, 1994). All other variables (hybrid, row spacing, and population) were considered fixed. Regression analysis was used where appropriate. Analyses for 1997 were kept separate from 1998-99 due to a different set of hybrids used that year. Effects were considered significant in all statistical calculations if P-values < 0.05.

Results and Discussion

Weather over the three years of the study played an important part in the variability between years and between trial locations within years. In 1997, accumulated growing-degree-days (GDD) (Table 1.3) were on average 403 GDD below the 30-year average, ranging from 165 to 491 GDD below normal. Precipitation (Table 1.4) in 1997, on average, remained near normal and ranged from 1.5 inches below average to 5.3 inches above the 30-year average. This cooler than normal season delayed crop physiological maturity until mid-November. The 1998 and 1999 growing seasons exceeded the 30-year average for GDD accumulation. The range of accumulated GDD over locations for 1998 was 206 below normal and 491 above normal. The 1999 season ranged from 12 GDD below to 412 GDD above the 30-year average. The largest accumulation of GDD occurred in the southeastern portion of the state where hot and dry conditions prevailed throughout the season. In 1999, there was a condition called "Growing-Degree-Day Compression" (Andresen, 1999) early in the growing season. Growing-Degree-Day Compression happens when there are small differences in GDD accumulations between central and southern growing areas within the state. These small differences in GDD are reflected in small differences in crop phenology between central and southern areas. Precipitation levels for the 1998 and 1999 growing season were 2.8 and 2.4 inches,

Table 1.3: Monthly growing degree day (GDD) [1] accumulations for the 1997-1999 growing seasons by regions. Thirty-year means have been included for comparison (1951-1980).

		Month						
Region	Year	May	June	July	Aug.	Sept.	Total	DEV
Central	1997	185	533	589	468	380	2155	-369
	1998	456	529	630	627	488	2730	206
	1999	399	595	740	555	415	2704	180
	30 yr.	338	530	640	598	418	2524	
Saginaw Valley	1997	170	550	601	469	372	2162	-491
	1998	465	586	701	695	512	2959	306
	1999	378	600	700	540	423	2641	-12
	30 yr.	367	555	670	623	438	2653	
Thumb	1997	109	518	577	432	349	1985	-350
	1998	391	500	609	622	498	2620	285
	1999	343	590	697	520	426	2576	241
	30 yr.	298	479	602	569	387	2335	
South East	1998	509	622	719	697	545	3092	491
	1999	437	645	811	617	503	3013	412
	30 yr.	353	542	658	616	432	2601	
South West	1998	473	557	681	681	512	2904	197
	1999	419	616	762	554	436	2786	79
	30 yr.	373	562	681	641	450	2707	

[1] GDD calculated at base 50°F, with 50°F and 86°F cutoffs.
Data courtesy of the MSU Agricultural Weather Office.

Table 1.4: Monthly accumulated precipitation (inches) for the 1997- 1999 growing season. Thirty-year means have been included for comparison (1951-1980).

		Month						
Region	Year	May	June	July	Aug.	Sept.	Total	DEV
Central	1997	2.7	2.3	2.5	3.3	5.2	15.9	1.0
	1998	1.5	2.7	2.7	3.9	1.5	12.2	-2.8
	1999	2.1	2.0	4.1	2.1	2.0	12.3	-2.6
	30yr.	3.0	2.7	3.5	3.1	2.5	14.9	
Saginaw Valley	1997	3.1	1.0	2.8	3.5	3.3	13.7	-0.8
	1998	1.2	1.8	1.3	1.5	1.9	7.6	-6.8
	1999	2.3	1.9	4.5	1.8	3.2	13.7	-0.7
	30yr.	2.8	2.5	3.1	3.3	2.8	14.5	
Thumb	1997	4.8	1.3	3.3	5.5	4.4	19.4	5.3
	1998	1.4	1.9	1.8	3.2	4.2	12.4	-1.7
	1999	2.4	2.7	6.5	1.7	3.5	16.8	2.7
	30yr.	2.9	2.6	2.9	3.0	2.7	14.1	
South East	1998	0.8	1.8	3.4	5.1	0.6	11.8	-4.1
	1999	3.5	2.0	2.0	1.3	1.0	9.8	-6.1
	30yr.	3.7	3.0	3.3	3.2	2.6	15.9	
South West	1998	1.8	4.4	2.9	8.4	2.0	19.4	2.7
	1999	1.7	2.8	3.5	2.8	1.9	12.6	-4.1
	30yr.	3.2	3.9	3.5	3.3	2.9	16.7	

Data courtesy of the MSU Agricultural Weather Office.

respectively, below the 30-year average. Precipitation ranged from 6.8 inches below in the central areas to 2.7 inches above in some southern areas in 1998. In 1999, precipitation ranged from 6.1 inches below in the southeast to 2.7 inches above in the central regions.

Over the course of the three years, all plots were harvested and planted in a timely manner (Table 1.5). However, in 1997, due to some last minute equipment changes plots were planted later than intended. A drier than normal spring in 1998 allowed for an early planting season in the Central Zones. More normal planting conditions returned in 1999, and planting was finished by May 11. Harvesting was delayed until mid-November in 1997 due to the higher levels of precipitation and cooler temperatures throughout the growing season. The 1998 and 1999 seasons had a warm, dry fall, allowing corn grain to reach harvest moisture early and harvest to be completed earlier than normal.

Table 1.5: Planting and harvesting dates.

	Planting Date			Harvest Date		
Region	1997	1998	1999	1997	1998	1999
Central	May 20	April 30	May 6	Nov. 8	Oct. 3	Oct. 2
Saginaw Valley	May 24	April 29	May 10	Nov. 11	Sept. 29	Oct. 5
Thumb*	May 24	May 14	May 10	Nov. 11		Oct. 5
South East		May 13	May 5		Oct. 13	Oct. 11
South West		May 11	May 11		Oct. 26	Oct. 12

* Location not harvested in 1998 due to poor emergence.

Statistical analyses were conducted separately for 1997. The summary of the 1997 ANOVA table (Table 1.6) shows the significance of the main effects of hybrids, row spacing, population, and their interactions. Locations were significant for all traits measured due to the variability in yield from north to south. When residuals were analyzed for each location, the graphs were similar in shape but shifted up or down depending on yield levels. Differences between hybrids were not significant for grain

Table 1.6: 1997 summary of combined analysis of variance for grain yield (GY), percent grain moisture (%H2O), test weight (TSTW), and stalk lodging (SL).

Source of variation	GY	%H2O	TSTW	SL
	P-values from ANOVA[1]			
Location	0.0001	0.0001	0.0001	0.0001
Hybrid	0.0542	0.0001	0.0001	0.0002
Row Spacing	0.0126	0.4819	0.6867	0.0001
Hyb*Row	0.3951	0.3019	0.4546	0.9822
Population	0.0001	0.0860	0.3879	0.0001
Hyb*Pop	0.9327	0.3112	0.0024	0.0056
Row *Pop	0.0607	0.7986	0.9709	0.4631
Hyb*Row*Pop	0.5871	0.0601	0.6314	0.9845

[1] Probability P=0.05

yield but were significant for moisture, test weight, and lodging. Differences between row spacing was significant for grain yield and lodging (Table 1.8). The absence of a hybrid x row spacing interaction would indicate that, of the hybrids investigated, hybrid selection was not critical for determining yield advantage in narrow row production. Plant population was found to influence grain yield and grain moisture at harvest. Corn grain moisture at harvest was influenced by a hybrid x row spacing x population interaction, which may be indicative of an individual hybrid's ability to tolerate stress.

Grain test weight was influenced by a hybrid x population interaction, which may indicate how kernel size might be affected by plant population pressures.

The ANOVA table (Table 1.7) is summarized for the 1998-99 growing seasons for the main effects of hybrid, row spacing, and plant population, along with the respective interactions. Location had the greatest affect on stalk lodging. Hybrid effect on grain yield was statistically significant in 1997 but not in 1998 or 1999. When yield was summarized by corn maturity zones, differences between hybrids evaluated in the Central Zone were not significant (Table 1.8). However, yields among hybrids in the Southern Zone were significantly different. This difference in significance may be due to the varying types of hybrids used in the Southern Zone. Row spacing affected grain yield, grain moisture, and stalk lodging but not test weight. In 1998-99, there was no hybrid x row spacing interaction. Plant population affected all variables. The hybrid x population

Table 1.7: 1998 and 1999 summary of combined analysis of variance for grain yield (GY), percent grain moisture (%H2O), test weight (TSTW), and stalk lodging (SL).

Source of variation	GY	%H2O	TSTW	SL
	P-values from ANOVA[1]			
Location	0.0001	0.1934	0.4022	0.9702
Hybrid	0.0001	0.0001	0.0001	0.0001
Row Spacing	0.0001	0.0001	0.7751	0.0077
Hyb*Row	0.2862	0.1649	0.8450	0.1408
Population	0.0001	0.0001	0.0001	0.0004
Hyb*Pop	0.0050	0.0001	0.0104	0.1317
Row*Pop	0.1579	0.0272	0.3910	0.8963
Hyb*Row*Pop	0.0077	0.7436	0.8578	0.0227

[1] Probability P=0.05

interaction had an effect on all variables except lodging. Row spacing x population interaction affected only grain moisture content. The hybrid x row spacing x population interaction affected both grain yield and lodging.

Table 1.8: Summary of combined analysis of variance for grain yield, comparing significance between central and southern zones in 1998 and 1999.

Source of variation	Central Zone	Southern Zone
	P-values from ANOVA[1]	
Location	0.0001	0.0001
Hybrid	0.0542	0.0001
Row Spacing	0.0126	0.4819
Hyb*Row	0.3951	0.3019
Population	0.0001	0.0860
Hyb*Pop	0.9327	0.3112
Row *Pop	0.0607	0.7986
Hyb*Row*Pop	0.5871	0.0601

[1] Probability P=0.05

Grain Yield

The factor with the most influence on yield was plant population. As plant population increased so did grain yield (Figure 1.1). However, yields were not always significantly different at the higher population levels. Row spacing affected grain yield. In 1998 and 1999, the 15-inch rows resulted in greater yields in the Central Zone than did the 22- and 30-inch row widths. The Central Zone in 1997 had a lower than normal GDD accumulation and higher than normal precipitation for the season, resulting in relative

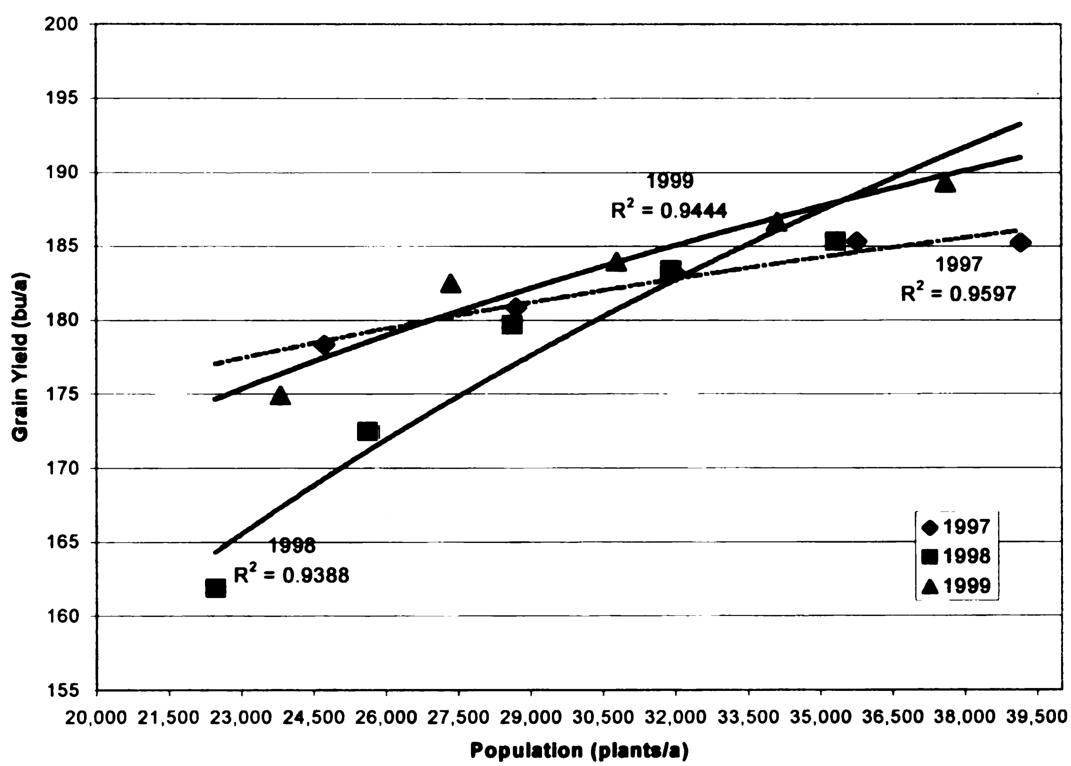

Figure 1.1: Grain yield response across row spacing to population by years; 1997, 1998 and 1999. Regression equations for predicting grain yield from population by years are:
1997 - $y = 16.252Ln(x) + 14.179$
1998 - $y = 52.092Ln(x) - 357.66$
1999 - $y = 29.416Ln(x) - 120.11$

yields with 15-inch rows that were not consistent with those obtained in 1998 and 1999 (Table 1.9). In 1997, the 22-inch row spacing had a 3.6 bushels per acre yield advantage over the 30-inch rows, but there was a 0.6 -bushel yield reduction when row width was reduced to 15-inches as compared to 30-inches. In the 1998 growing season, the Southern Zone had a 7.4 bushel yield advantage of 22-inch and 15-inch rows over the 30-inch

Table 1.9: Grain yield (bushels per acre) by row spacing with advantage over 30-inch rows for comparison.

Row Spacing	1997[1]	1998	1999	Avg. '98-'99.
	Central Zone			
30-inch	181.6b	162.7b	189.8b	176.6b
22-inch	185.1a	163.9b	193.4b	178.6b
15-inch	181.0b	168.9a	200.6a	184.7a
	Central Zone Advantage of Narrow Rows over 30-inch			
22-inch	3.6	----[2]	----	----
15-inch	----	6.1	10.8	8.5
	Southern Zone			
30-inch		180.0b	171.3a	175.6b
22-inch		187.3a	171.5a	179.4ab
15-inch		187.3a	173.4a	180.3a
	Southern Zone Advantage of Narrow Rows over 30-inch			
22-inch		7.4	----	----
15-inch		7.4	----	4.9

[1] Grain yields within year and zones followed by the same letter are not significantly different.
[2] Comparison is not significantly different.

rows. The Central Zone, in 1998, had only a 1.2 and 6.1 bushel yield advantage for the 22-inch and the 15-inch row spacings, respectively, over the 30-inch rows. These differences may be due to the inadequate rainfall that occurred in the Central Zone in 1998. The weather conditions were reversed for the 1999 growing season, resulting in a 10.8 bushels per acre yield advantage of the 15-inch rows over the 30-inch rows in the central zone. This deviation from the 30-year norm would indicate that narrow rows tend to have a greater yield advantage over wide rows when water is not a limiting factor (Stickler, 1964; Fulton, 1970) and when planted at higher populations (Hoff and Mederski, 1969; Fulton, 1970).

Hybrid selection was crucial to grain yield. The later maturing hybrids generally had the yield advantage with a few exceptions. In 1999, yields in the Central Zone were above. In 1998, the central zone did not yield as well due to drought conditions. Yields in the southern zone were hindered in 1998 and 1999 due to higher accumulation of heat units and lower precipitation. Hybrid yield was also dependent upon the interaction of the hybrid with plant population level and how well each hybrid could withstand stress. Yield averages of individual hybrids ranged from 169.8 - 195.6 bushels per acre (Table 1.10).

Table 1.10: Grain yield (bushels per acre) by hybrid, year, and zone. Hybrids are listed in order of maturity within year and zone.

Hybrid	1997[1]	1998	1999	Avg.
		Central Zone		
PIO 3751	185.5a			185.5a
GL 4929	180.8a			180.8a
GRST 8735	178.0a			178.0a
GRST 8640	185.7a			185.7a
Max 86		157.0b	196.1a	176.5a
RK 552		167.7a	194.6a	181.1a
GL 4758		163.8a	195.8a	179.8a
PIO 3573		172.0a	192.0a	182.0a
		Southern Zone		
GL 4758		177.8b	173.6b	175.7b
PIO 3573		182.5b	167.6b	175.1b
GL 5715		173.0b	166.5b	169.8b
RK 775		206.2a	181.0a	193.6a

[1] Grain yields within year and zones followed by the same letter are not significantly different.

Grain Moisture

Grain moistures were strongly correlated with hybrid maturity. The later maturing hybrids usually had the highest grain moisture content at harvest (Table 1.11). There were differences in grain moisture across years, corresponding with the different growing conditions within each year. Grain moisture content was higher for the 1997 season, ranging from 25.7 - 28.5 % due to the cool, wet growing conditions. Grain moisture in 1998 and 1999 was much drier due to the higher accumulated GDD.

Table 1.11: Grain moisture (percent) by hybrid, year, and zone. Hybrids are listed in order of maturity within year and zone.

Hybrid	1997[1]	1998	1999	Avg.
		Central Zone		
PIO 3751	25.7c			25.7c
GL 4929	27.8ab			27.8ab
GRST 8735	27.6b			27.6b
GRST 8640	28.5a			28.5a
Max 86		20.0c	19.0b	19.5b
RK 552		18.9d	17.4c	18.1c
GL 4758		21.5b	19.2b	20.4b
PIO 3573		22.9a	20.5a	21.7a
		Southern Zone		
GL 4758		18.4b	18.3b	18.4b
PIO 3573		18.9b	18.0b	18.4b
GL 5715		21.0a	19.7a	20.3a
RK 775		20.7a	18.6b	19.6a

[1] Grain moisture levels within year and zones followed by the same letter are not significantly different.

The 22-inch row spacing in 1997 had a higher grain moisture content than did the 30-inch rows. In all other incidences, the narrow rows were drier than the 30-inch rows. The difference in grain moisture ranged from 0.01 to 0.70 % (Table 1.12).

Table 1.12: Grain moisture (percent) by row spacing.

Row Spacing	1997[1]	1998	1999	Avg. '98-'99
		Central Zone		
30-inch	27.4a	21.1a	19.1a	20.1a
22-inch	27.5a	21.0a	19.0a	20.0a
15-inch	27.4a	20.4b	19.0a	19.7b
		Southern Zone		
30-inch		20.0a	18.8a	19.4a
22-inch		19.6b	18.6b	19.1b
15-inch		19.7b	18.6b	19.1b

[1] Grain moisture levels within year and zones followed by the same letter are not significantly different.

In 1998 and 1999, as population increased from lowest to highest, the grain moisture dropped 0.4 and 0.7 %, respectively. In 1997, grain moisture increased slightly (0.3 %) as plant population increased (Figure 1.2).

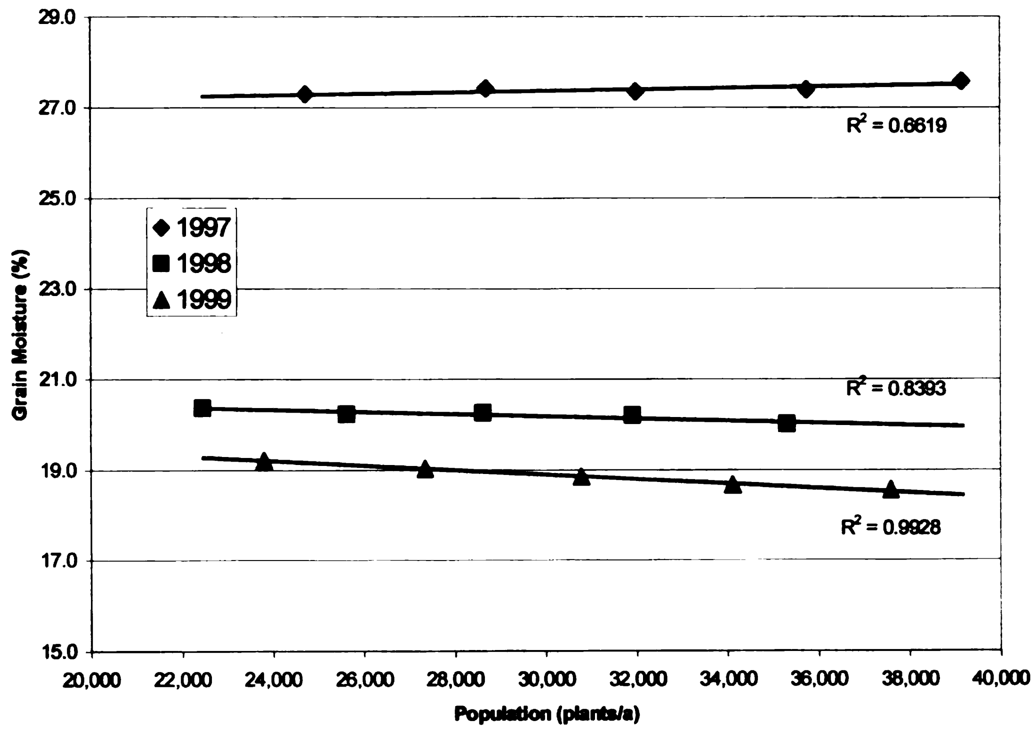

Figure 1.2: Grain moistures by year and populations. Regression equations for predicting grain moisture by years are:
1997 - y = 2E-05x + 26.91
1998 - y = -2E-05x + 20.896
1999 - y = -5E-05x + 20.37

Test Weight

The inherent differences in the hybrids evaluated had the greatest impact on grain test weight at harvest. There was a strong negative correlation between test weights and grain moisture. As grain moisture increased, test weight decreased. This correlation was most evident when the test weight for 1997, where gain moistures were high (see Table 1.11),

Table 1.13: Test weights (pounds per bushel) by hybrid, year, and zone. Hybrids are listed in order of maturity within year and zone.

Hybrid	1997[1]	1998	1999	Avg.
		Central Zone		
PIO 3751	52.8a			52.8a
GL 4929	50.1b			50.1b
GRST 8735	52.5a			52.5a
GRST 8640	49.5c			49.5c
Max 86		61.6a	59.4a	60.5a
RK 552		56.2b	55.0b	55.6b
GL 4758		57.0b	55.7b	56.4b
PIO 3573		55.0c	53.8c	54.5c
		Southern Zone		
GL 4758		59.2a	61.1a	60.2a
PIO 3573		58.1b	59.5b	58.8b
GL 5715		59.3a	61.1a	60.2a
RK 775		55.4c	59.7b	57.5c

[1] Test weights within year and zones followed by the same letters are not significantly different.

is compared with the test weight results from 1998 and 1999 (Table 1.13). Grain test weight on average was 51.2, 57.7, and 58.2 pounds per for 1997, 1998, and 1999, respectively. Row spacing did not affect grain test weight when test weight was averaged by row with. (Table 1.14). Again, there were differences between years, due to higher grain moisture in 1997. The differences were consistent across all row spacings.

Table 1.14: Test weights (pounds per bushel) by zone, year, and row spacings.

Row Spacing	1997[1]	1998	1999	Avg.'98-'99
		Central Zone		
30-inch	51.3a	57.7a	55.9a	56.8a
22-inch	51.2a	57.4b	56.1a	56.8a
15-inch	51.2a	57.2b	56.0a	56.6a
		Southern Zone		
30-inch		58.0a	60.3a	59.2a
22-inch		57.7a	60.3a	59.1a
15-inch		58.0a	60.4a	59.2a

[1] Test weights within year and zones followed by the same letter are not significantly different.

Plant population also affected grain test weight. As plant population increased, grain test weight tended to increase (Figure 1.3). The exception to this was, once again in 1997, when the test weight dropped 0.01 pounds as plant population increased from lowest to highest. In 1998 and 1999, the test weight increased 0.04 and 0.50 pounds, respectively, as population increased. The large difference in grain test weight between the 1997 and 1998-1999 growing season is again due to the higher grain moisture at harvest.

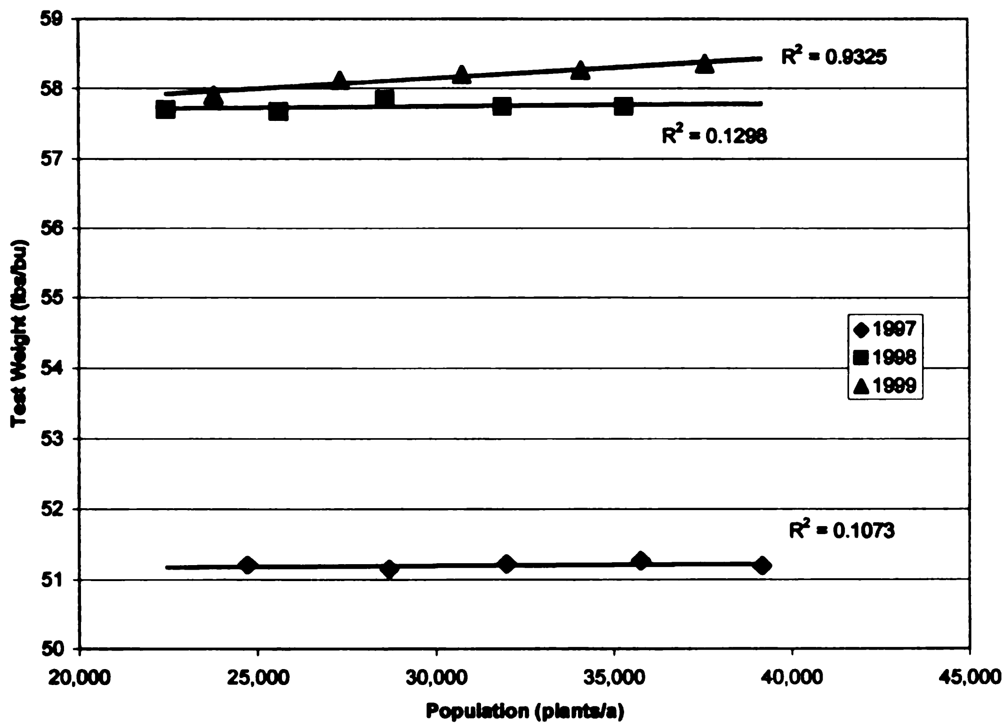

Figure 1.3: Test weight by year and population. Regression equations for prediction test weight from population by years are:
1997 - y = 3E-06x + 51.126
1998 - y = 5E-06x + 57.604
1999 - y = 3E-05x + 57.234

Stalk Lodging

Stalk lodging was most affected by the inherent characteristics of the hybrids selected for this test. Each individual hybrid could withstand stress to some degree (Table 1.15). The amount of stalk lodging also appeared to be dependent on the different environmental conditions within each year. The 1997 growing season had the highest level of stalk lodging.

Table 1.15: Percent stalk lodging by hybrid, year, and zone. Listed in order of hybrid maturity within year and zone.

Hybrid	1997[1]	1998	1999	Avg.
		Central Zone		
PIO 3751	7.6a			7.6a
GL 4929	3.9b			3.9b
GRST 8735	2.8b			2.8b
GRST 8640	3.5b			3.5b
Max 86		0.3b	1.4b	0.8b
RK 552		0.4b	5.0a	2.7a
GL 4758		0.3b	4.4a	2.4a
PIO 3573		0.9a	4.8a	2.8a
		Southern Zone		
GL 4758		0.4b	0.9b	0.6b
PIO 3573		1.6a	1.6ab	1.6a
GL 5715		0.4b	1.0b	0.7b
RK 775		1.3ab	2.4a	1.9a

[1] Stalk lodging within year and zones followed by the same letter are not significantly different.

When row spacing narrowed, the percentage of stalk lodging increased (Table 1.16). The largest increase in stalk lodging was found in 1997 when the 22-inch rows showed a 1.3% increase in stalk lodging and the 15-inch rows exhibited a 1.5% increase in stalk lodging over the 30-inch rows. The average of the 1998-1999 growing seasons showed the 22-inch rows had a 0.1 % reduction in stalk lodging in the Central Zone and a 0.6% increase in stalk lodging in the Southern Zone compared to corn grown in 30-inch rows. The 15-inch rows had a 0.2% reduction of stalk lodging in the Central Zone. In the Southern Zone, the 15-inch rows had a 0.1 % increase in stalk lodging.

Table 1.16: Percent stalk lodging by zone, hybrid, year, and row spacing.

Row Spacing	1997[1]	1998	1999	Avg. '98-'99
		Central Zone		
30-inch	3.5b	0.4a	4.1a	2.24a
22-inch	4.8a	0.5a	3.9a	2.18a
15-inch	5.0a	0.5a	3.7a	2.07a
		Southern Zone		
30-inch		0.82a	1.1b	1.0b
22-inch		1.14a	2.0a	1.6a
15-inch		0.78a	1.4b	1.1b

[1] Stalk lodging within year and zones followed by the same letter are not significantly different.

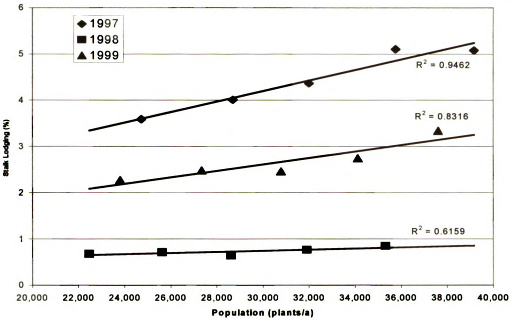

Figure 1.4: Percent stalk lodging by year and population. Regression equations for predicting stalk lodging from population by years are:
1997 - y = 0.0001x + 0.7871
1998 - y = 1E-05x + 0.3674
1999 - y = 7E-05x + 0.5109

Stalk lodging increased as plant population increased (Figure 1.4). Stalk lodging in 1998 was much less than in the other two years of the study, resulting in only a 0.2 % increase in stalk lodging as plant population increased from lowest to highest. In 1997, stalk lodging increased 1.5 % as plant population increased. Stalk lodging increased 1.1 % in 1999.

Conclusion

This data indicates that of the parameters measured, plant population had the greatest influence on yield. As plant population increased, so did grain yield. Differences in yield, however, were not always significant at the higher plant populations. This increase in yield indicates that by increasing plant population, yield may be increased without changing row width. Care should be taken when choosing hybrids. Corn hybrids with good stress tolerance, that can withstand high populations without producing barren plants, should be chosen. When planting 30-inch rows, plant population should start at about 32,000 plants per acre and then be adjusted up or down, depending upon the soil type, fertility level, and the water-holding capacity of the soil. As row spacing narrows, the inter-row competition is reduced, allowing plant population to be increased. When considering planting corn in 15-inch rows, plant population may be set at about 36,000 plant per acre and adjusted up or down, depending upon the soil conditions stated above. For 22- inch rows, plant populations should begin at about 34,000 plants per acre and adjusted according to the soil conditions.

Data over the three-year duration of this study indicates that there is a yield advantage in planting corn in row spacings narrower then 30-inch rows. The data indicated that 15-inch rows have a yield advantage over 30-inch rows in the central growing zone by at least 8.5 bushels per acre. This data showed, in the southern growing zones, the yield advantage was 4.9 bushels per acre. Twenty-two inch row spacings had a 2.4-bushel yield advantage in the Central Zone over the 30-inch rows. The yield advantage of the 22-inch row spacings over the 30-inch row spacings was 3.8 bushels per acre when the 22-inch rows were planted in the southern growing zone. Corn producers in the central growing zone had a greater yield advantage when corn was planted in the 15-inch rows. This supports the findings of Steve Paszkiewicz (1997) who, summarizing data from 84 locations across the Corn Belt, concluded that areas north of I-90 had the greatest advantage for narrow rows. Cox et al. (1998) summarizing Paskiewiez's work suggested the greatest yield response to narrow rows was above the 44°N Latitude. The data from the 1997 to 1999 growing seasons indicated that narrow rows in Michigan have a greater yield advantage in the Michigan maturity zones two or greater.

Grain moisture, test weight, and stalk lodging are all strongly influenced by the inherent characteristics of the corn hybrid selected. The selection of a later-maturing hybrid tends to increase the grain moisture at harvest and this, in turn, reduces test weight. Later-maturing hybrids, when harvested with higher grain moisture content, tend to not have problems with stalk lodging because the plant has not started to deteriorate as rapidly. Higher population is an important element in improving yield, coupled with hybrid selection. The next logical step to increase yield is to reduce plant competition within the row by reducing row width. The reduction in row width allows the plant to better utilize soil nutrients and moisture. Narrow rows also increase the canopy density, allowing the corn to more efficiently harvest sunlight, resulting in increased yields.

References

Andresen, J. 1999. 1999 Growing season weather summary. *In* Corn hybrids compared in the 1999 season. Michigan State University Extension Bulletin E-431.

Bullock, D. G., R. L. Nielsen, and W. E. Nyquist. 1988. A growth analysis comparison of corn grown in conventional and equidistant plant spacing. Crop Sci. 28:254-258.

Cox, W. J., D. R. Cherney, and J. J. Hanchar. 1998. Row Spacing, hybrid, and plant density effects on corn silage yield and quality. J. Prod. Agric., 11:128-134.

Hume, A. N., O. D. Center, and A. Hegnauer. 1908. Distance between hills of corn in the Illinois Corn Belt. Illinois Experiment Station Bulletin 126.

Fulton, J. M. 1970. Relationships among soil moisture stress, plant populations, row spacing and yield of corn. Can. J. Plant Sci. 50:31-38.

Johnson, G. A., T. R. Hoverstad, and R. E. Greenwald. 1998. Integrated weed management using narrow corn row spacing, herbicides, and cultivation. Agron. J. 90:40-46.

Krall, J. M., H. A. Esechie, R. J. Raney, S. Clark, G. TenEyck, M. Lundquit, N. E. Humburg, L. S. Axthelm, A. D. Dayton, and R. L. Vanderlip. 1997. Influence of within-row variability in plant spacing on corn grain yield. Agron. J. 69:797-799.

Kuehl, R. O. 1994. Complete Block Designs. *In* Statistical Principles of Research Design and Analysis. Duxbury Press.

Murphy, S., Y. Yakubu, S. F. Weise, and C. J. Swanton. 1996. Effect of planting patterns and inter-row cultivation on competition between corn (Zea mays) and late emerging weeds. Weed Science 44:856-870.

Nafziger, E. D. 1996. Effects of missing and two-plant hills on corn grain yield. J. Prod. Agri. 9:238-240.

Nafzinger, E. D. 1994. Corn planting date and plant population. J. Prod. Agric. 7:59-62.

Nielson, R. L. 1988. Influence of hybrids and plant density on grain yield and stalk breakage in corn grown in 15-inch row spacing. J. Prod. Agric. 1:190-195.

Ottman, M. J. and L. F. Welch. 1989. Planting patterns and radiation interception, plant nutrient concentration, and yield in corn. Agron. J. 81:167-174

Paszkiewicz, S. 1997. Narrow row width influence on corn yield. *In* Proc. 51st Annu. Corn and Sorghum Res. Conf., Chicago, IL. Am. Seed Trade Assoc., Washington DC.

Porter, P. M., D. R. Hicks, W. E. Lueschen, J. H. Ford, D. D. Warnes, and T. R. Hoverstad. 1997. Corn response to row width and plant population in the northern corn belt. J. Prod. Agric. 10:293-300.

Rossman, E. C., and R. L. Cook. 1966. Soil preparation and date, rate, and pattern of planting. *In* W. H. Pierrce, S. A. Aldrich, and W. P. Maring (eds). Advances in corn production: Principles and practices. Iowa State Univ. Prss.

Rounds, W. T., E. C. Rossman, W. Zurakowski, and E. E. Down. 1951. Method, and date of planting corn. Michigan Agr. Exp. Sta. Quart. Bull. 33:372-87.

SAS Institute. 1985. SAS user's guide: Statistics. 5th ed. SAS Inst., Cary, NC.

Scheifele, G., S. Jay, and J. Horn. 1996. 1991-1996 Research report for narrow row corn production in southwestern Ontario. Agronomy Department, Ridgetown College of Agricultural Technology, Ridgetown, Ontario, N0P 2C0.

Stickler, F. C. 1964. Row width and plant population studies with corn. Agron. J. 56:438-441.

Thomison, P. R. and D. M. Jordan. 1995. Plant population effects on corn hybrids differing in ear growth habit and prolificacy. J. Prod. Agric. 8:394-400.

Tollenaar, M. 1989. Genetic improvement in grain yield of commercial maize hybrids grow in Ontario from 1959 to 1988. Crop Sci. 29:1365-1371.

Tollenaar, M. 1991. Physiological basis of genetic improvement of maize hybrid in Ontairo from 1959 to 1988. Crop Sci. 31:119-124.

Westgate, M. E., F. Forcella, D. C. Reicosky, and J. Somsen. 1997. Rapid canopy closure for maize production in the northern US corn belt: Radiation-use efficiency and grain yield. Field Crops Research 49:249-258.

CHAPTER 2

EFFECT OF ROW SPACING, PLANT POPULATION AND PLANTING DATE ON HYBRID CORN PRODUCTION IN MICHIGAN

Abstract

New corn hybrids (*Zea mays* L.) have improved genetics allowing them to better withstand stress better. With the improved genetics comes the ability for the hybrid seedlings to withstand cooler growing conditions. Producers can take advantage of higher yielding, longer maturing hybrids by planting them earlier in cooler soils. An earlier planting date in effect increases the length of the growing season. It has been proven that earlier planted corn will out yield corn been planted later in the season. When producers are considering utilizing a narrow row system they need to consider wither the architecture of a narrow row canopy will affect the optimum planting date. A two year study was conducted at Michigan State University to determine the effect of planting date, row spacing, and plant population on corn grain production in Michigan. Three planting dates of April 27th, May 12th, and May 25th were selected. These planting dates with the two-week intervals span typical planting date range in Michigan. Three hybrids were selected so that one of the hybrid's maturity best matched one planting date. The three hybrids were planted at 30-, 22-, and 15-inch row spacings. Each combination of planting date, hybrid, and row spacing were planted at 26K, 32K, and 38K plant per acre. The plots were planted in a split-split-split plot arrangement. In 1998, the advantage of earlier planted corn was negated by weather patterns favoring later

plantings. This abnormal weather pattern produced inconclusive results on how planting date effects corn yield. There was, with each increase in plant population, an increase in grain yield. In 1998, the 15-inch row out yielded the 30-inch row at the later planting dates by 7.9 bushels/acre. In 1999, the 15-inch row had a 15.2-bushel yield increase over the 30-inch row. Grain moisture content increased as planting dates were delayed. Moisture content was also highest in the later maturing hybrids. Test weight was closely correlated to the moisture content of the grain. As moisture content of the grain increased test weight declined. Seasonal differences and hybrid characteristics affected stalk lodging more than any other variable. Plant and ear height increased as planting date was delayed and when plant population increased.

Introduction

New corn hybrids (*Zea mays L.*) are being introduced to the market each year with better and improved genetics. Contemporary hybrids have greater cold tolerance and seedling vigor, which have allowed for earlier planting dates. Earlier planting dates, in turn, enable producers to take advantage of fuller season hybrids. Full season hybrids, which take longer to mature, generally have a yield advantage over shorter season hybrids (Harpstead and Dysinger, 1998). Early planting dates lengthen the effective growing season for corn, thereby increasing the chance for corn to reach physiological maturity before a killing frost. This facilitates faster dry down of grain, which can reduce production cost.

There are trade offs between planting date and corn maturity. Planting full season hybrids will generally provide larger yields. But, if physiological maturity is not reached, gains in yields will be offset by higher drying cost. Regardless of the maturity of the hybrid, yield declines as the date of planting is earlier or delayed from the optimum planting date. (Imholte and Carter, 1987; Swanson and Wilhelm, 1996; Nafziger, 1994; Staggenborg et al., 1999). Yields of full season hybrids decline at a greater rate than do short season hybrids as the planting date is delayed (Lauer et al., 1999). Rossman and Cook (1966) summarized 14 years of data in Michigan, between 1949 and 1963, and concluded corn grain yields for early May plantings were 9% higher than mid-May plantings, 16% higher than late May plantings, and 27% higher than June plantings.

Late planting dates and low plant populations can reduce corn grain yield (Nafziger, 1994; Benson, 1990). Hybrids developed in the last few years are able to withstand higher populations better than older hybrids. Optimum planting densities were lower for hybrids released in the 1960's than for hybrids released in the 1980's, due to better stress tolerance (Tollenaar, 1989). Tollenaar reported that contemporary hybrids could withstand high populations better because of a decrease in stalk lodging. Tollenaar (1991) also reported that modern-day hybrids withstand stress better and do not produce as many barren plants when subject to high plant populations. Thomison and Jordan (1995) reported hybrid ear type was of limited importance in determining optimum plant densities. Nafziger (1994) evaluated two hybrids with reportedly different responses to plant density and found no significant hybrid x plant population interaction.

The yield advantage of early planted corn is due to increased radiation interception (Pendleton and Egli, 1969). Other ways to increase radiation interception is to manipulate the canopy architecture by changing plant population and row spacing. The redistribution of radiation to lower leaves of the plant is beneficial because lower leaves are more efficient at low levels of radiation (Loomis and Williams, 1969). Narrow row production systems reduce interplant competition, thus allowing more radiation to reach the lower leaves of the corn plant. The lower leaves of the plant are primary sources of carbohydrates for the roots (Palmer et al., 1973; Fairey and Daynards, 1978). Wide rows (30-inches) consistantly intercepted less photosynthetically active radiation (PAR) than did narrow rows (10- and 15- inches) (Forcella et al., 1992). The plant population level within narrow rows also changed the PAR interception. Narrow rows (20-inches) intercepted up to 7 and 11% more radiation than wider rows (40-inches), at a planting population of 28- and 32-thousand (Yao and Shaw, 1964).

The objective of this study was to determine the effect of planting date, row spacing, and plant population on corn grain yield, maturity, and lodging in Michigan.

Materials and Methods

Field studies were implemented in 1998 and 1999 at Michigan State University in East Lansing, MI on a Capac Loam soil that had been in a soybean [*Glycine max.* (L.) *Merr*] - corn rotation. Three planting dates were selected, which would cover the range of planting dates common for planting corn in Michigan. Planting dates selected were April 27th, May 12th, and May 25th. This allowed for two-week planting intervals. Corn was planted in 30-, 22-, and 15-inch row spacings. Each of the row spacings were planted at three population levels (low, medium, and high) with a target population of 26-, 32-, and 38-thousand plants per acre, respectively. The experiments were arranged as a split-split-split plot with a randomized complete block design. The date of planting represented the main plots (198 by 30 feet), hybrid represented the first split (66 by 30 feet), row spacing represented the second split (66 by 10 feet), and plant population was the final split (22 by 10 feet). This experimental design allowed the effects of planting date, hybrid, row spacing, population, and their interactions to be observed.

Three corn hybrids were selected from hybrids well adapted for the growing conditions in mid-Michigan (Dysinger et at., 1997). Relative hybrid maturities were selected so one hybrid would best fit the maturity for each planting date. Hybrids were also selected based upon differing ear and plant physical characteristics (Table 2.1).

Table 2.1: Hybrid maturity and agronomic characteristics. Hybrids are listed in order of maturity.

Company	Hybrid	Maturity	Ear Type	Height
Novartis	Max 86	93 day	Determinate	Tall
DeKalb	DK 493	99 day	Indeterminate	Medium
Pioneer	PIO 3491	107 day	Flex	Short

Temperature probes were inserted 2-inches into the soil at the root zone of the medium population plots representing each planting date and row spacing. Plant populations were determined in all plots after corn emerged. Plots were hand thinned if populations exceeded target levels for that plot. For 1999, light interception measurements were taken for each plot, as close to solar noon as possible and then averaged by treatment.

Light interception readings were taken beginning at 8, 7, and 6 weeks after planting for the planting dates of April 23rd, May 14th, and May 25th, respectively. Plant and ear height measurements were taken for each plot after pollination. Ear height was measured from the ground to the node of attachment. Plant height measurements were taken from the tip of the tassel to the ground. Stalk lodging observations were recorded at harvest.

Plots were harvested mechanically for corn grain. Moisture content and field weights were automatically measured by the GrainGage™, a HarvestData System™ mounted on a plot combine. Grain yields were reported at a standard 15.5% moisture. Test weights were recorded and reported at harvest moisture.

All data was analyzed using analysis of variance (ANOVA) and the Mixed Linear Model in SAS Statistical Software Package version 6.12 (1989-1996 SAS Institute Inc., Cary, NC). The Mixed Linear Model is able to calculate the appropriate error terms for tests associated with the split-split-split plot design. Mean separations between all variables were obtained by Tukey's Least Significant Difference Test. All variables were considered fixed (planting date, hybrid, row spacing, and population). Regression analysis was used where appropriate. Effects were considered significant in all statistical calculations if P-values < 0.05.

Results and Discussion

Similar weather patterns occurred in 1998 and 1999. The 1998 growing season had near normal precipitation between May and August (Table 2.2). Precipitation for September was markedly lower than the 30-year average. Over all, the 1998 season ended with a precipitation deficit of 1.6 inches as compared to the 30-year average. In 1998, growing-degree-day (GDD) accumulation was 144 GDD below normal. Most of the accumulated GDD for the season occurred in the later part of May, and August through September. Precipitation was 3.4 inches below the 30-year average for the 1999-growing season. However, timely precipitation (6.8 inches) in July and August increased kernel set at pollination and facilitated kernel fill. This precipitation helped boost yields for the season. Growing degree-day accumulation for the 1999 growing season was near normal.

Table 2.2: Monthly precipitation (inches) and growing-degree-day (GDD) accumulation for the 1998 and 1999 growing seasons. Thirty-year means have been included for comparison (1951-1980).

	Precipitation			Growing Degree Days[1]		
Month	1998	1999	30 yr.	1998	1999	30 yr.
May	2.73	1.78	2.73	442	385	338
Jun	2.51	1.07	3.54	522	474	530
July	2.83	4.75	3.02	618	729	640
August	3.94	2.09	3.12	617	551	598
September	1.29	1.84	2.50	471	424	418
Seasonal Total	13.30	11.53	14.91	2668	2562	2524
DEV[2]	-1.61	-3.38		144	38	

[1] GDD calculated for corn at a base 50^{O}F, with a 50^{O}F and 86^{O}F cutoffs.
[2] The deviation from the 30-year mean.
Data recorded at the Horticultural Research Station, East Lansing, MI.

Dry field conditions in both 1998 and 1999 allowed plots to be planted in a timely manner (Table 2.3). Lower precipitation in 1999 allowed harvesting of plots earlier than in 1998. Both years had drier and warmer than average conditions at harvest.

Table 2.3: Planting and harvesting dates for the date of planting study for 1998 and 1999.

	Planting Date		Harvesting Date	
Trial	1998	1999	1998	1999
Date 1	April 25	April 29	October 4	September 25
Date 2	May 9	May 14	October 11	September 25
Date 3	May 23	May 27	October 19 and October 23	October 3

Soil Temperatures

Soil growing degree accumulations recorded within rows and averaged over two years indicated that a 15-inch row canopy kept soil temperatures cooler (Figure 2.1). Soil growing degree monthly accumulations under corn canopies peaked in June, after which time they decreased due to shading within the row. The accumulation of growing degrees was slower in bare soils due to radiation loss early in the season. This loss was caused by cool nights with no canopy cover to trap heat reflectance from the soil. Bare soils, once warmed, tended to hold heat longer because of increased direct radiation later in the season. Soil under a corn canopy tended to accumulate less growing degrees than bare soil.

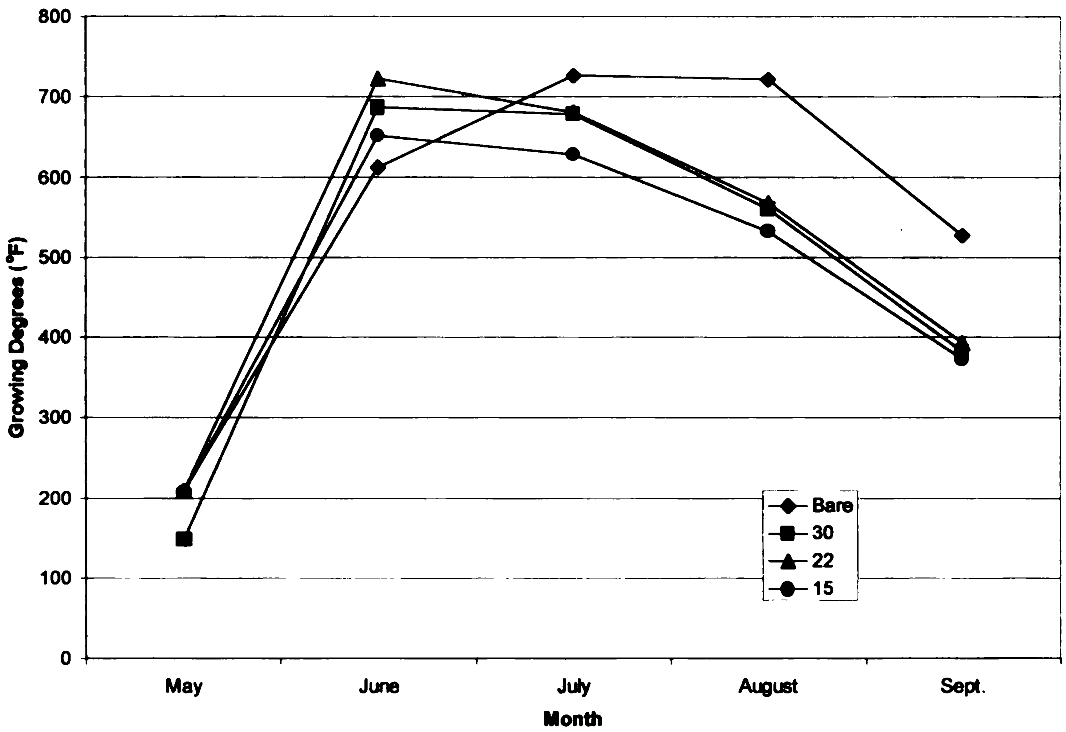

Figure 2.1: Soil growing degree accumulations by row spacing and month.

Light Measurements

The percent of PAR intercepted by the corn canopy varied by planting date. The percent of PAR intercepted by the corn canopy is dependent on the height of the canopy, which is in direct relationship to the growth stage of the plant. Corn planted at the later planting dates intercepted greater percent of PAR than did the earlier planted corn after the 195th day of the year (Figure 2.2). The percent of PAR intercepted by hybrids also increased as planting date was delayed from April 29th (Figure 2.3). Row spacing also affected the percent of intercepted PAR. Corn grown in 15-inch rows always intercepted the highest percentage of PAR (Figure 2.4). As planting date was delayed, all treatments, regardless of row spacing, had an increase in intercepted PAR. The lowest plant populations

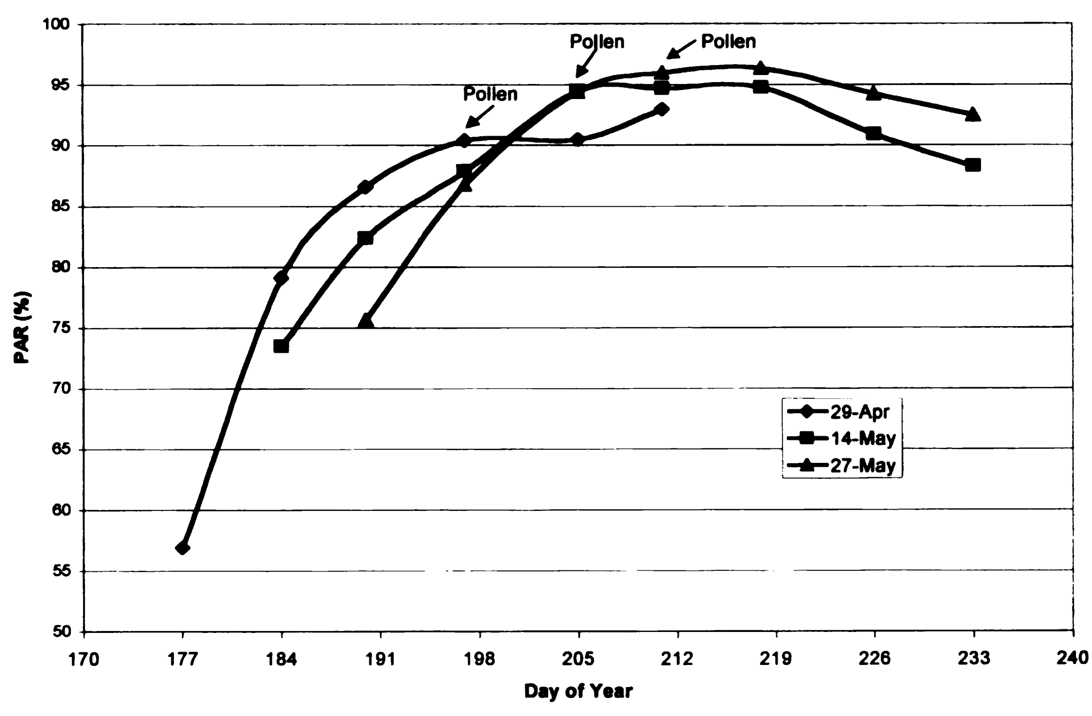

Figure 2.2: Percent intercepted PAR by planting date and day of year.

intercepted the least percent of PAR. Higher plant populations also intercepted more PAR as planting dates were delayed (Figure 2.5).

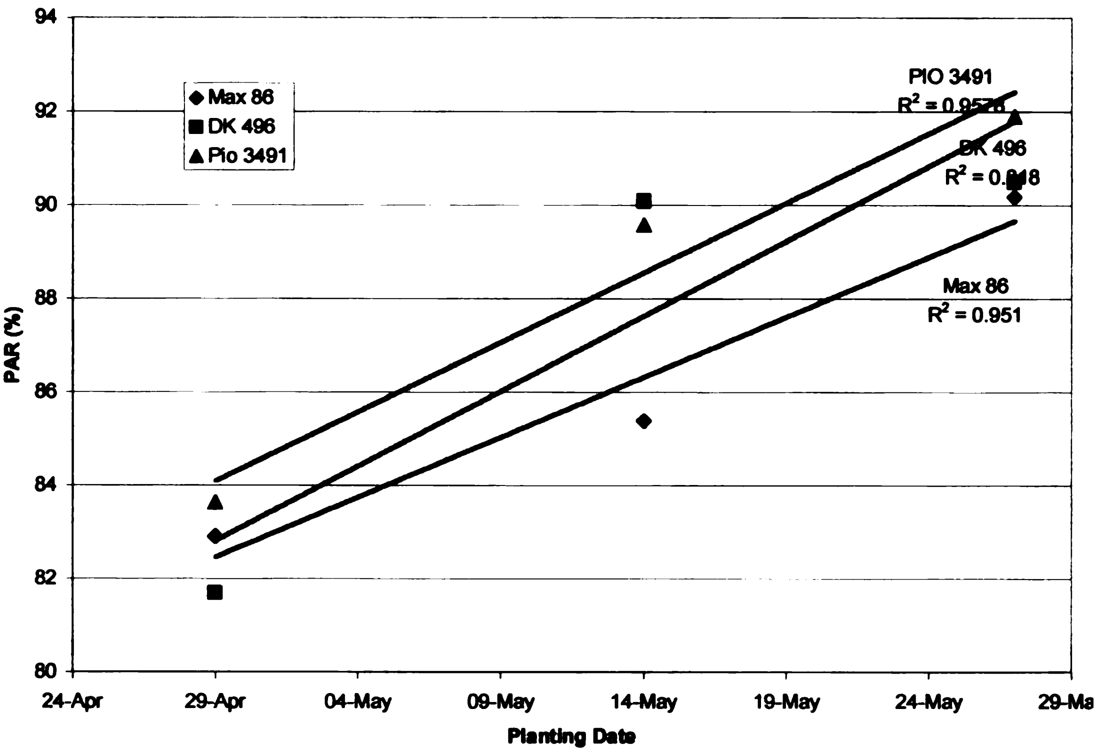

Figure 2.3: Percent intercepted PAR by planting date and hybrid. Regression equations for predicting percent PAR from planting date by hybrids are:
Max 86 - y = 9433.2Ln(x) - 99051
DK 496 - y = 11762Ln(x) - 123523
PIO 3491 - y = 10914Ln(x) - 114608

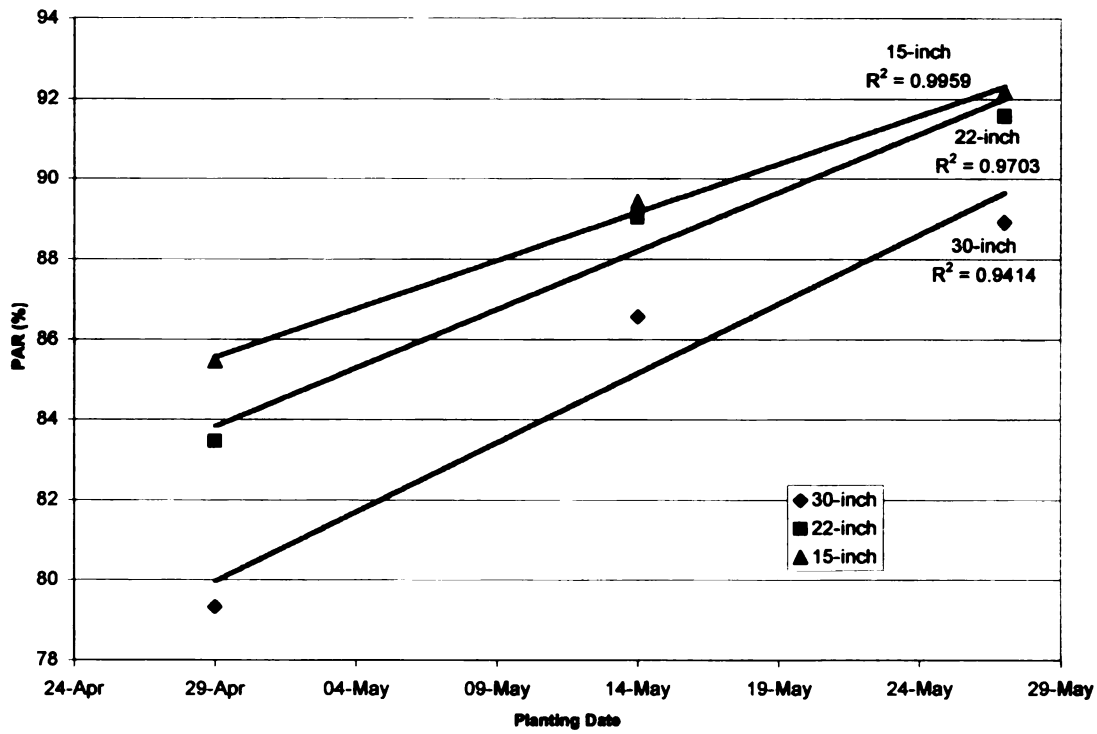

Figure 2.4: Percent intercepted PAR by planting date and row spacing. Regression equations for predicting percent PAR from planting date by row spacing are:
30-inch - y = 12683Ln(x) - 133202
22-inch - y = 10708Ln(x) - 112444
15-inch - y = 8840.8Ln(x) - 92823

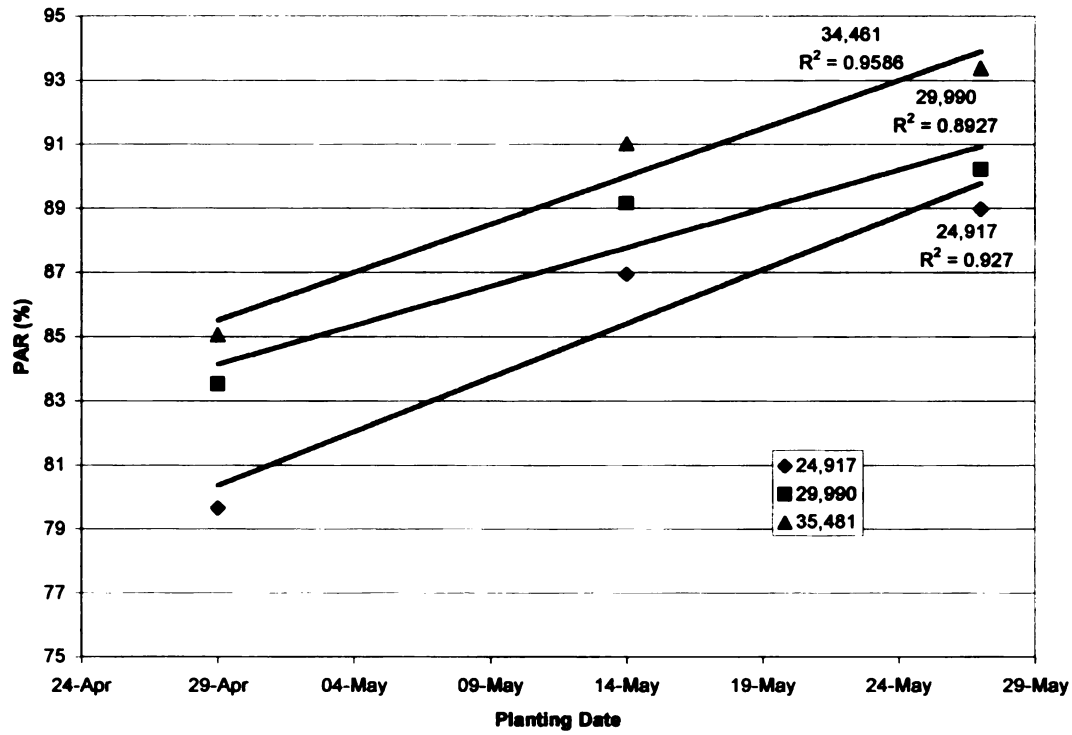

Figure 2.5: Percent intercepted PAR by planting date and population. Regression equations for predicting percent PAR from planting date by population levels are:
24,917 - y = 12354Ln(x) - 129751
29,990 - y = 8909.4Ln(x) - 93545
35,461 - y = 10988Ln(x) - 115388

Statistical analyses were combined over the two years of the study. The summary of the ANOVA table (Table 2.4) shows the significance of the main effects of planting date, hybrid, row spacing, population, and their interactions. Years were significant for test weight and stalk lodging only. Planting date was significant for percent grain moisture, test weight, and plant and ear height, but not grain yield. The lack of a response of grain yield to planting date could be due to environmental conditions, which favored later planted corn. Hybrids were significant for all traits: grain yield, grain moisture, test weight, stalk lodging, and plant and ear height. The main effect of row spacing was only significant for grain yield. Plant population was significant for grain yield, grain

Table 2.4: Planting date summary of combined analysis of variance for grain yield (GY), percent grain moisture (%H2O), grain test weight (TSTW), stalk lodging (SL), plant height (PLH), and ear height (ERH) for 1998 and 1999.

Source of Variation	GY	%H2O	TSTW	SL	PLH	ERH
	P-values from ANOVA[1]					
Year	0.2178	0.5504	0.0001	0.0009	0.7475	0.9892
Planting Date	0.2611	0.0001	0.0001	0.6405	0.0090	0.0034
Hybrid	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Date*Hyb	0.5979	0.5368	0.0307	0.0087	0.5581	0.7503
Row Spacing	0.0004	0.3297	0.2444	0.4718	0.7563	0.3663
Date*Row	0.1465	0.0045	0.3052	0.2971	0.0978	0.5821
Hyb*Row	0.2276	0.8983	0.3064	0.5234	0.1222	0.2623
Date*Hyb*Row	0.0988	0.5231	0.0854	0.2686	0.9828	0.9307
Population	0.0001	0.0443	0.5978	0.0010	0.0338	0.0001
Date*Pop	0.0036	0.1811	0.4719	0.7614	0.0102	0.2627
Hyb*Pop	0.7496	0.0169	0.0005	0.5228	0.5696	0.9706
Date*Hyb*Pop	0.1227	0.2990	0.0353	0.0822	0.7295	0.6352
Row*Pop	0.0241	0.5548	0.4536	0.9679	0.8562	0.7541
Date*Row*Pop	0.3883	0.0287	0.0121	0.1690	0.0156	0.6764
Hyb*Row*Pop	0.6617	0.0397	0.0038	0.7316	0.8334	0.0552
Date*Hyb*Row*Pop	0.8576	0.4251	0.0232	0.5839	0.9517	0.5773

[1]Probability P=0.05

moisture, stalk lodging, and plant and ear height. Two traits, test weight and stalk lodging, were affected by the planting date x hybrid interaction. The absence of a hybrid x row spacing interaction indicates that of the hybrids used, all responded similarly to differences in row spacing. Grain yield and plant height was affected by the planting date x population interaction. The hybrid x population interaction affected only grain moisture. The interaction of row spacing x population affected only the corn grain yield. The three-way interaction of planting date x hybrid x row spacing did not affect any of the traits observed. The planting date x hybrid x population interaction affected only test weight, while the planting date x row spacing x population interaction and the hybrid x row spacing x population interaction affected grain moisture and test weight. Grain test weight was the only trait affected by the four-way interaction of planting date x hybrid x row spacing x population.

Grain Yield

Typically corn grain yield is reduced as planting date is delayed, but in 1998 corn grain yield increased by 3.3 bushels per acre with delayed planting due to weather conditions in the spring which favored later planted corn (Figure 2.6). The grain yield in 1999 was reversed from that of 1998. When planting date was delayed in 1999, from April 27th to May 25th, yield decreased, on average, 15.4 bushels per acre.

Yield performance of the hybrids was positively correlated with the maturity of the hybrids. The later maturing hybrids out-yielded the shorter season hybrids. There were differences between hybrids on how they responded to the delay in planting dates (Table 2.5).

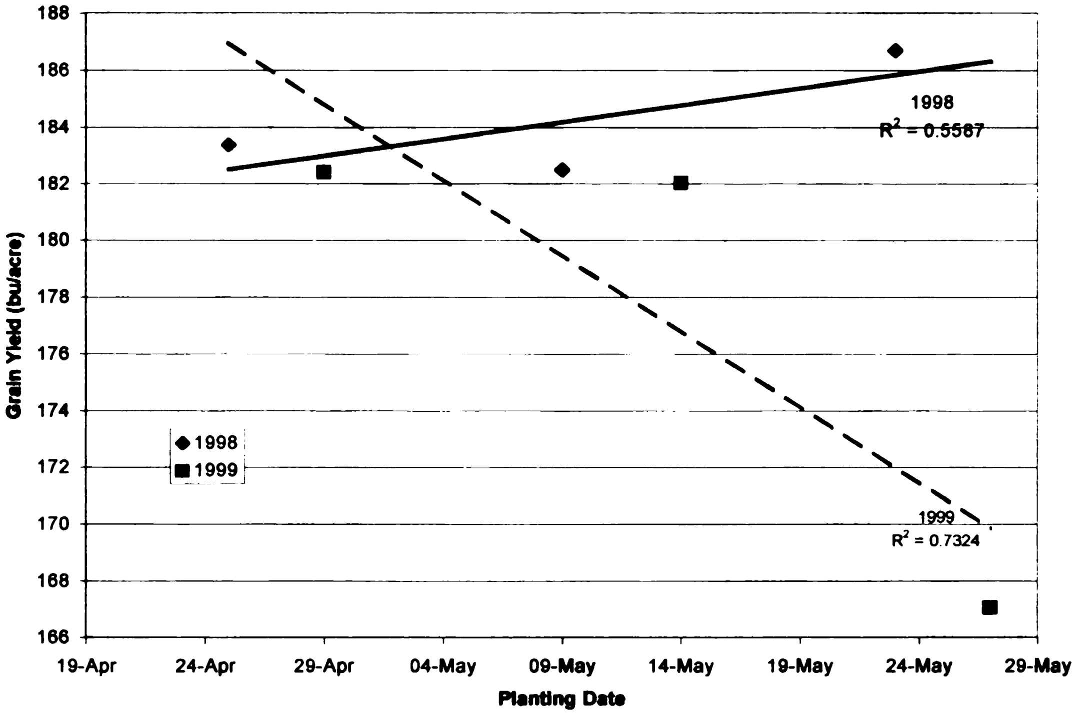

Figure 2.6: Grain yield by planting date and year. Regression equations for predicting grain yields from planting date by year are:
1998 - $y = 0.1188x - 4171$
1999 - $y = -0.5355x + 19808$

Table 2.5: Grain yield (bushels per acre) by hybrid, planting date, and year. Hybrids are listed in order of maturity.

Hybrid	Planting Date	1998[1]	1999	Average
Max 86	April 27	175.9b	172.8ab	174.4c
	May 12	177.3b	183.0ab	180.2abc
	May 25	181.3ab	164.0ab	172.7c
	Average[2]	178.2b	173.3b	175.7b
DK 493	April 27	170.9b	169.2ab	170.1c
	May 12	175.7b	165.4ab	170.5c
	May 25	173.8b	148.7cb	161.2c
	Average	173.5b	161.0b	167.3b
PIO 3491	April 27	203.3a	205.9a	204.6a
	May 12	194.5ab	197.7ab	196.1ab
	May 25	205.0a	188.5ab	196.7a
	Average	200.9a	197.3a	199.1a

[1] Grain yields for planting dates within year followed by the same letter are not significantly different.
[2] Average yield within year followed by the same letter are not significantly different

Row spacing was also a determining factor in grain yield. Corn planted in narrow rows consistently out-yielded the wider 30-inch rows except in 1999, when the 30-inch rows out-yielded the 22-inch rows for the May 12th planting date by 4.6 bushels per acre (Table 2.6). In 1998, the narrow rows had a yield advantage over the 30-inch rows in the later planting dates. The 22-inch rows had a 7.0 bushels per acre advantage on the May 12th planting date, while the 15-inch rows out-yielded the 30-inch rows by 7.9 bushels per acre on the later May 25th planting date. This trend was reversed in 1999, with the narrow 22- and 15-inch rows out-yielding the 30-inch rows by 10.38 and 15.2 bushels per acre, respectively, for the earliest planting date. When grain yield was averaged across years, corn grown in 15-inch rows had a yield advantage of 8.5 bushels per acre. Corn grown in the 22-inch row spacing out-yielded the corn grown in 30-inch rows by 7.9 bushels per acre. This increase in yield was observed at the earliest planting date. Corn grown in narrow rows out-yielded the 30-inch row corn when yield was averaged across

Table 2.6: Grain yield (bushels per acre) by row spacing, planting date, and year.

Row Spacing	Planting Date	1998[1]	1999	Average
30-inch	April 27	181.0ab	173.9b	177.4b
	May 12	179.0ab	182.9ab	181.0ab
	May 25	183.7b	166.5ab	175.2ab
	Average[2]	181.3b	174.4b	177.9a
22-inch	April 27	186.3ab	184.2ab	185.3a
	May 12	185.9ab	178.3ab	182.1ab
	May 25	184.5ab	168.2ab	176.3ab
	Average	185.6a	176.9ab	181.2a
15-inch	April 27	182.8ab	189.1a	186.0a
	May 12	182.5ab	184.9ab	183.7ab
	May 25	191.8a	166.5ab	179.1ab
	Average	185.7a	180.2a	182.9a
	Advantage of Narrow Row Over 30-Inch by Planting Date			
22-inch	27-Apr	---[3]	---	7.9
	12-May	---	---	---
	25-May	---	---	---
15-inch	27-Apr	---	15.2	8.5
	12-May	---	---	---
	25-May	7.9	---	---
	Advantage of Narrow Row Over 30-Inch Averaged across Planting Date			
22-inch	Average	4.3	---	---
15-inch	Average	4.4	5.8	---

[1] Grain yields for planting dates within year followed by the same letter are not significantly different.
[2] Average yield within year followed by the same letter are not significantly different.
[3] Comparison is not significantly different.

years for the two later dates. These differences in grain yield, however, were not as significant as the differences observed at the early planting date.

Grain yield increased as plant population increased. In 1998, as plant population increased from lowest to highest, yields increased 15.5 bushels per acre, or 10.3% (Figure 2.7). There was also a substantial increase in yield as the plant population increased for each planting date. As plant population increased, so did yield for each row spacing.

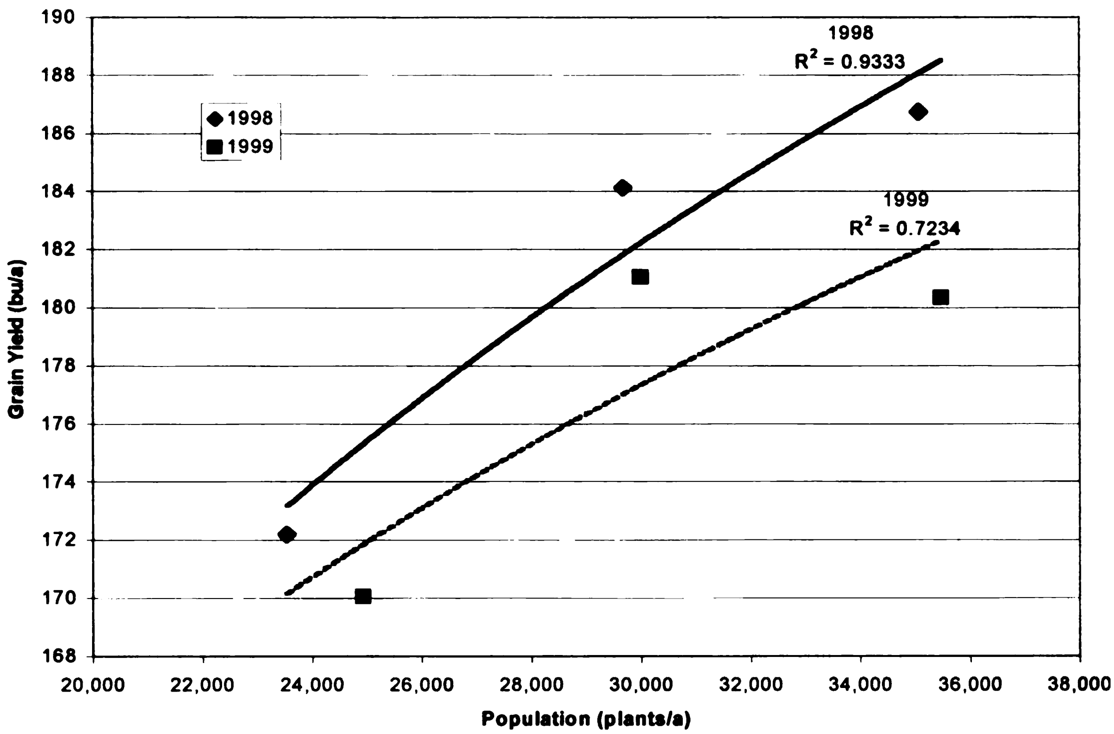

Figure 2.7: Grain yield by population and year. Regression equations for predicting grain yield from plant population by year are:
1998 - $y = 37.395\text{Ln}(x) - 203.25$
1999 - $y = 29.609\text{Ln}(x) - 127.91$

Grain Moisture

Late planted corn had the highest grain moisture at harvest. When averaged over 1998 and 1999, grain moisture increased as planting date was delayed. Grain moisture increased 4.7 % when planted on April 24th as compared to May 25th (Figure 2.8). Grain moisture followed hybrid maturity. Late maturing hybrids always had higher grain moisture (Figure 2.9). Grain moisture, when averaged over row spacing, increased 4.7% as planting date was delayed. When plant population was increased, grain moisture dropped 0.3% (Figure 2.10). This was also evident, but not as pronounced, when hybrids were averaged over populations.

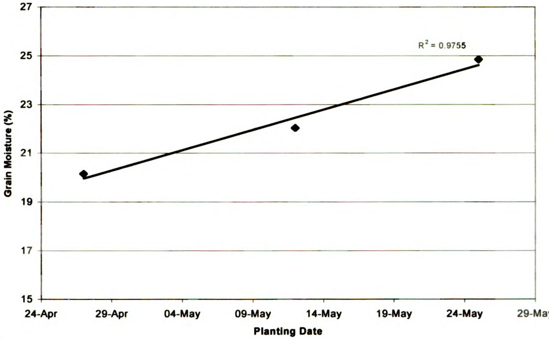

Figure 2.8: Grain moisture by planting date. Regression equations for predicting grain moisture from planting date is y = 0.1663x - 6074.6

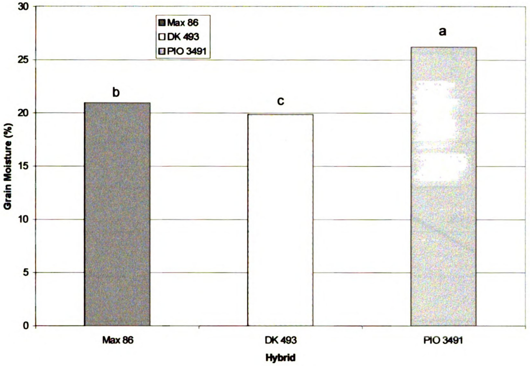

Figure 2.9: Grain moisture by hybrid. Hybrids are listed in order of maturity. Columns with the same letter are not significantly different.

Test Weight

Grain test weight was negatively correlated with grain moisture. When grain moisture increased, test weight tended to be reduced. Test weight, when averaged over planting date, was reduced by 3.3 lbs. in 1998, and 4.4 lbs. in 1999, as planting date was delayed (Figure 2.11). Hybrid maturity also affected test weight. The later maturing hybrids had consistantly higher grain moisture and tended to have lower test weights. There was a 6.0 lb difference in test weight with only a 14 day spread in relative hybrid maturity (Figure 2.12). Test weight for all hybrids declined as planting date was delayed. There were differences in test weight between hybrids as plant population increased, but not significant enough to be an effective management tool.

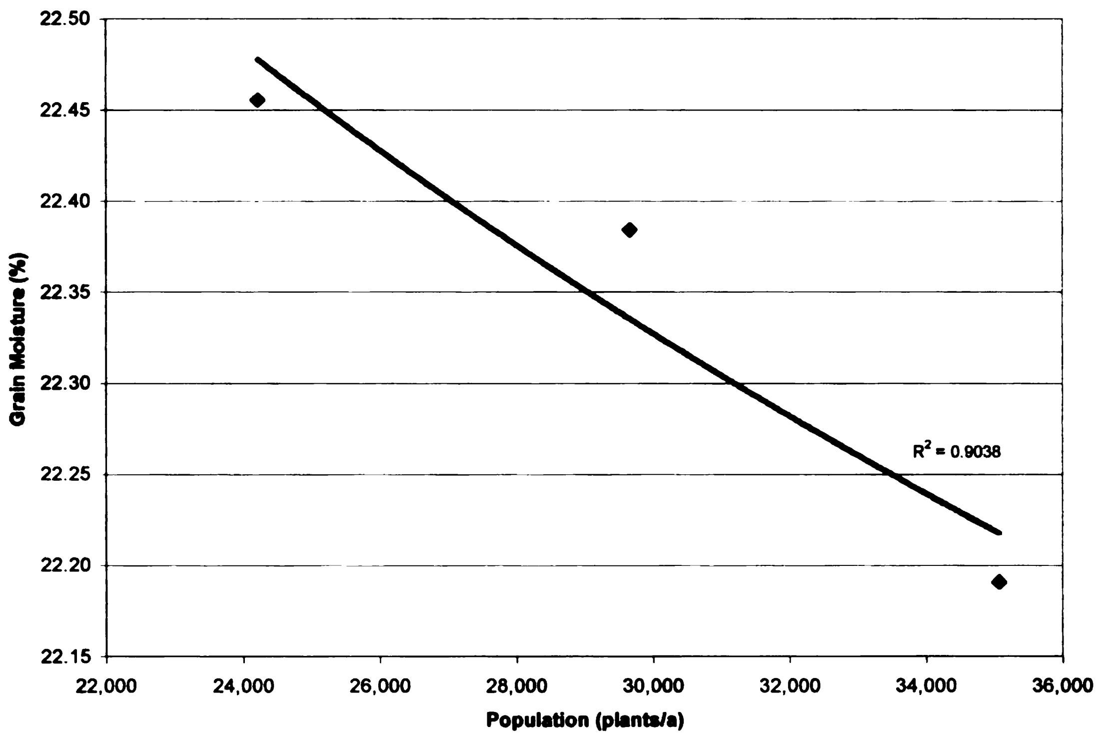

Figure 2.10: Grain moisture by population. Regression equations for predicting grain moisture from population is y = -0.7034Ln(x) + 29.579

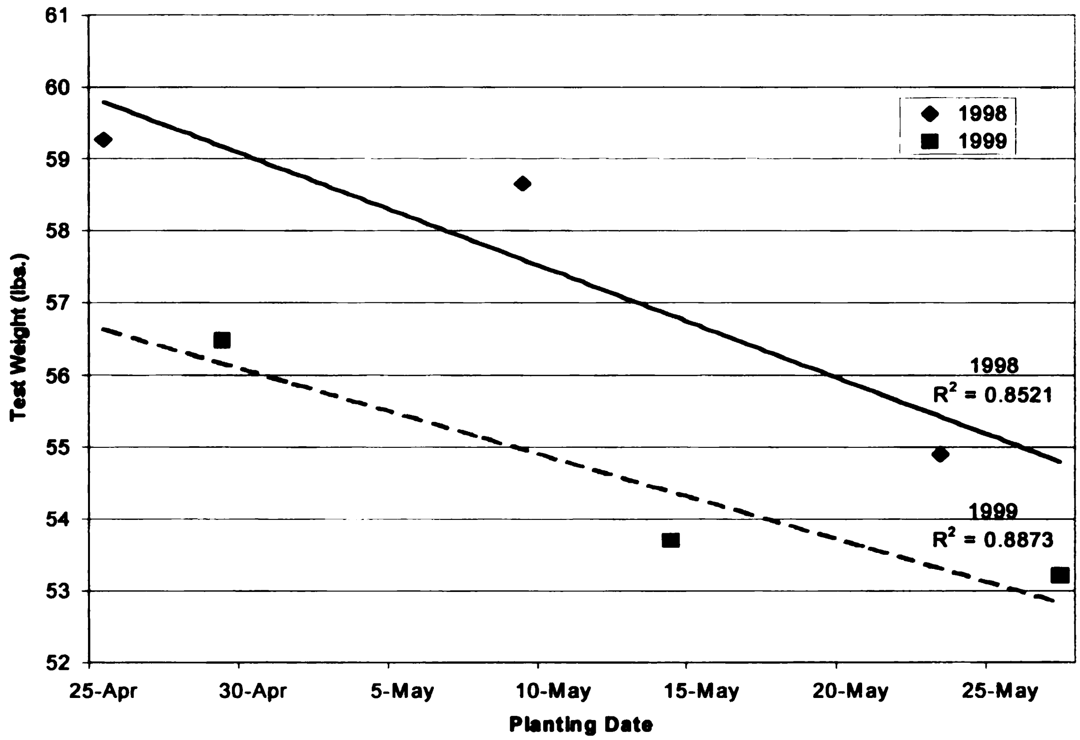

Figure 2.11: Test weight by planting date and year. Regression equations for predicting test weight from planting date by year are:
1998 - y = -5725.9Ln(x) + 60232
1999 - y = -4354.4Ln(x) + 45817

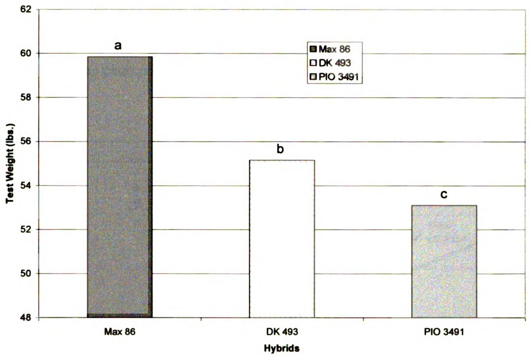

Figure 2.12: Test weight by hybrid. Hybrids are listed in order of maturity. Columns with the same letter are not significantly different.

Stalk Lodging

The different weather patterns between the two years of the study had varying impacts on stalk lodging. For the 1998 growing season, stalk lodging was reduced by 0.8% when the planting date was delayed from April 2nd to May 25th. Stalk lodging in 1999 increased 1.3% when the planting date was delayed for the same period of time (Figure 2.13). There was a difference in stalk lodging between hybrids as well. On average, the earlier maturing hybrids had fewer stalks lodged than did the later maturing hybrids (Figure 2.14). The latest maturing hybrid, PIO 3491, had a 1.9% increase in stalk lodging when planting dates were delayed from April 27th to May 25th. The earliest maturing hybrids, Max 86 and DK 493, had a 0.5% and 0.6% decrease in stalk lodging, respectively, for the same delay in planting date (Figure 2.15). Plant population also affected stalk lodging. As plant population increased, so did the number of plants lodged. Stalk lodging increased 0.7% as plant population increased from lowest to highest (Figure 2.16).

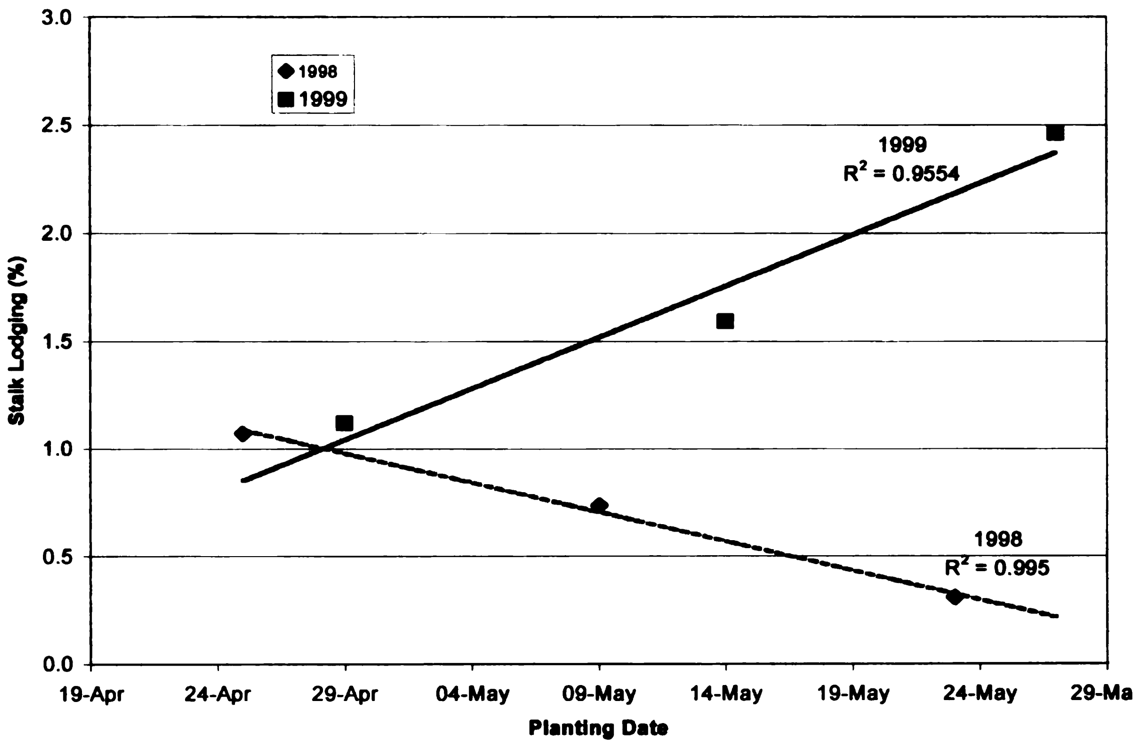

Figure 2.13: Stalk lodging by planting date and year. Regression equations for predicting stalk lodging from planting date by years are:
1998 - $y = -997.58Ln(x) + 10485$
1999 - $y = 1743.4Ln(x) - 18321$

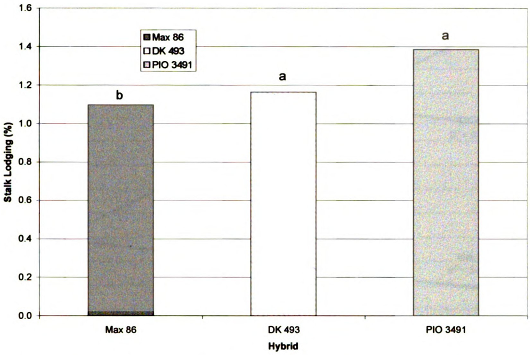

Figure 2.14: Stalk lodging by hybrid. Hybrids are listed in order of maturity. Columns with the same letter are not significantly different.

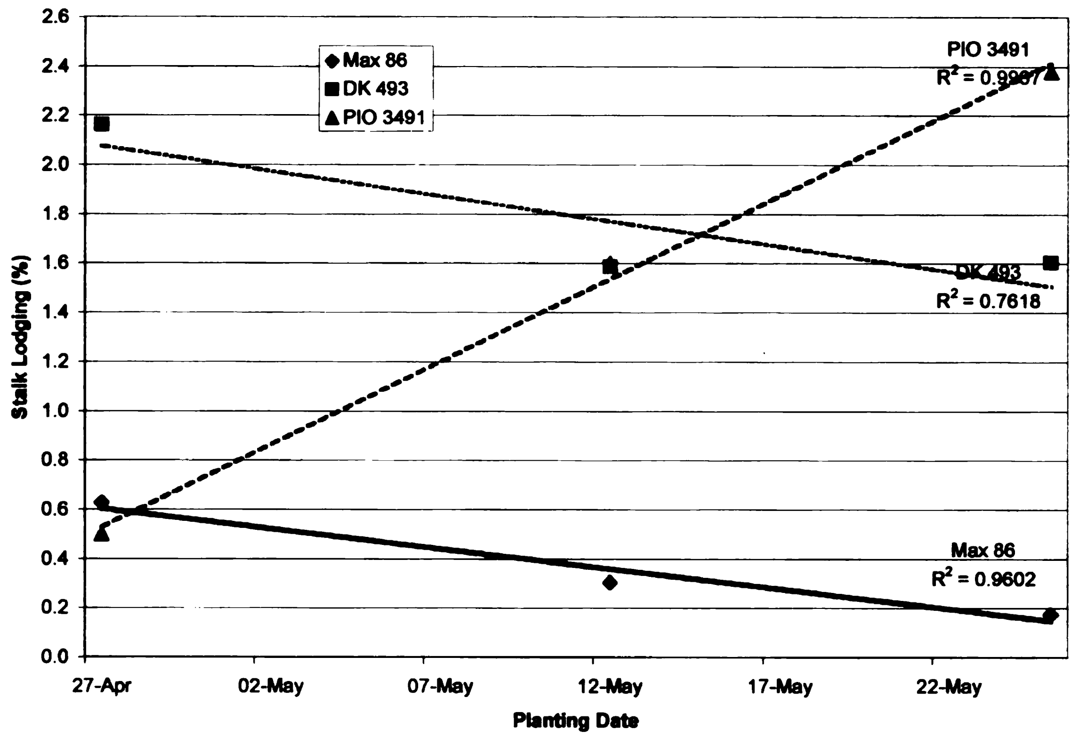

Figure 2.15: Stalk lodging by planting date and hybrid. Regression equations for predicting stalk lodging by hybrids are:
Max 86 - $y = -595.96Ln(x) + 6263.6$
DK 493 - $y = -746.4Ln(x) + 7846$
PIO 3491 - $y = 2467.8Ln(x) - 25934$

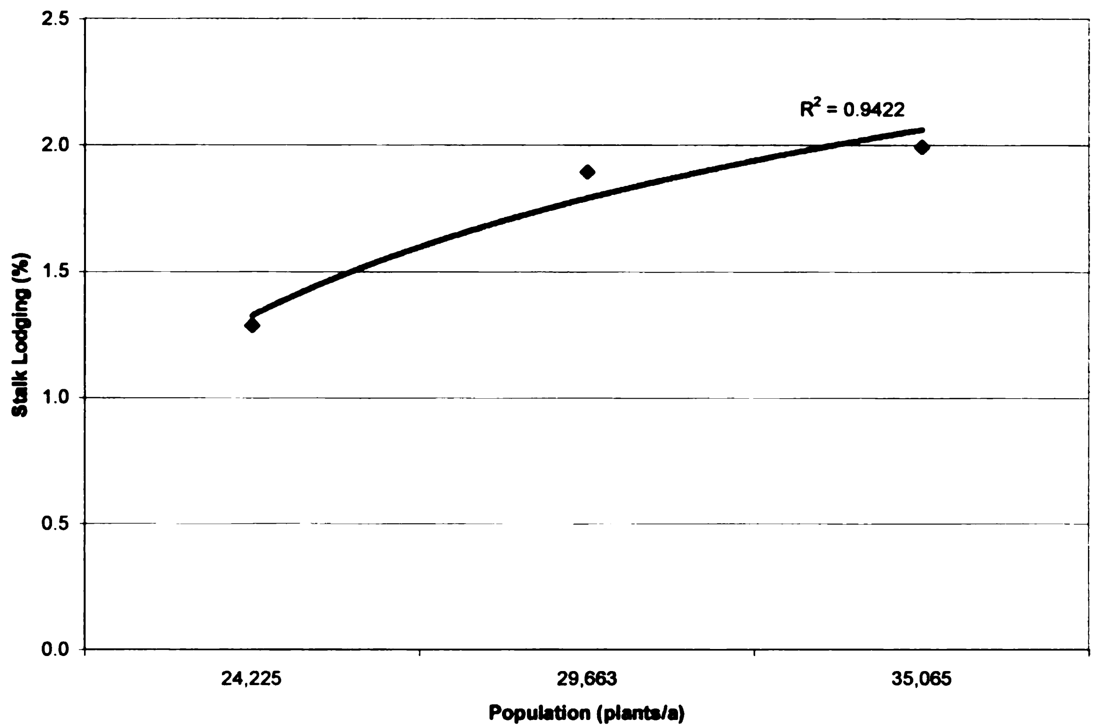

Figure 2.16: Stalk lodging by population. Regression equation for predicting stalk lodging from population is y = 0.6698Ln(x) + 1.324.

Plant Height

Plant height changed with planting date. Corn hybrids planted early in the season were usually shorter in stature than later planted corn. When plant height was averaged over the two years of the study, and by planting date, the earliest planted corn was the shortest at 109.1 inches (Figure 2.17). As planting date was delayed until May 12th, corn height was 113.5 inches, which was an increase of 4.3 inches. When planting date was delayed to May 25th, there was a 3.4 inch increase in height compared to the earliest planted corn. Hybrid characteristics also influence the height of the corn. The hybrids PIO 3491, Max 86, and DK493 were 118.2, 110.1, 106.4 inches tall, respectively (Figure 2.18). Plant population also influenced plant height. Plant height increased as plant population increased. When plant height was averaged over plant population, there was a 1.2 inch increase in plant height. As plant population was averaged over planting date, the last planting date of May 24th had a reduction in plant height at the highest population. All other planting dates had an increase in plant height as population increased.

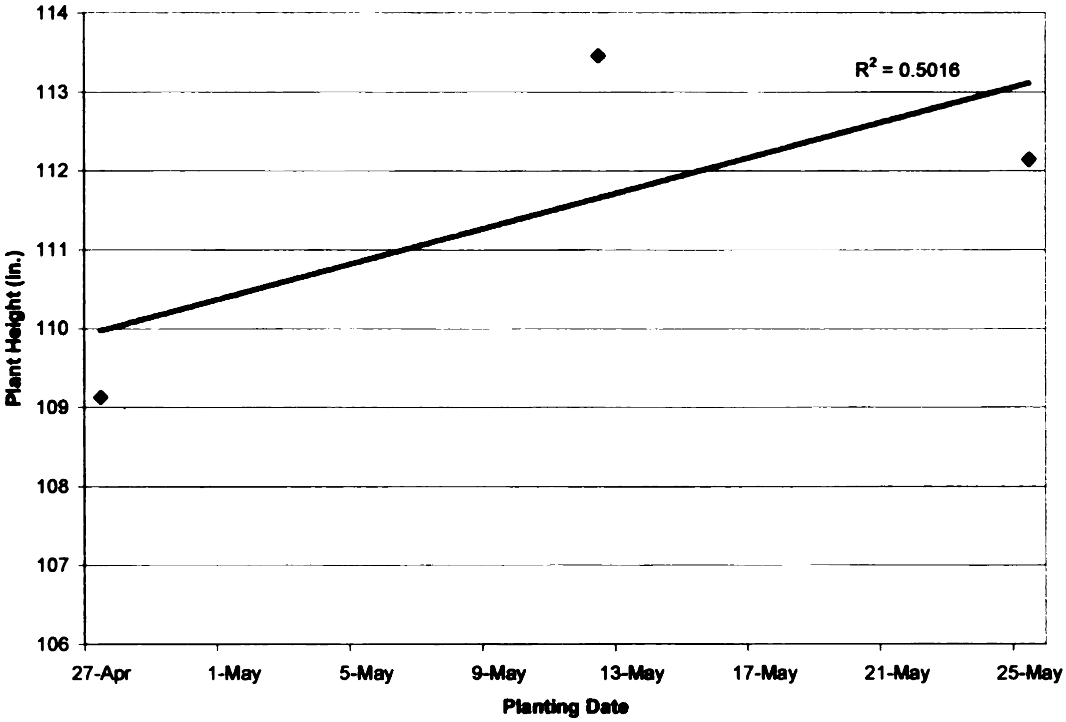

Figure 2.17: Plant height by planting date averaged over 1998 and 1999. Regression equations for predicting plant height from planting is y = 4116.5Ln(x) - 43150.

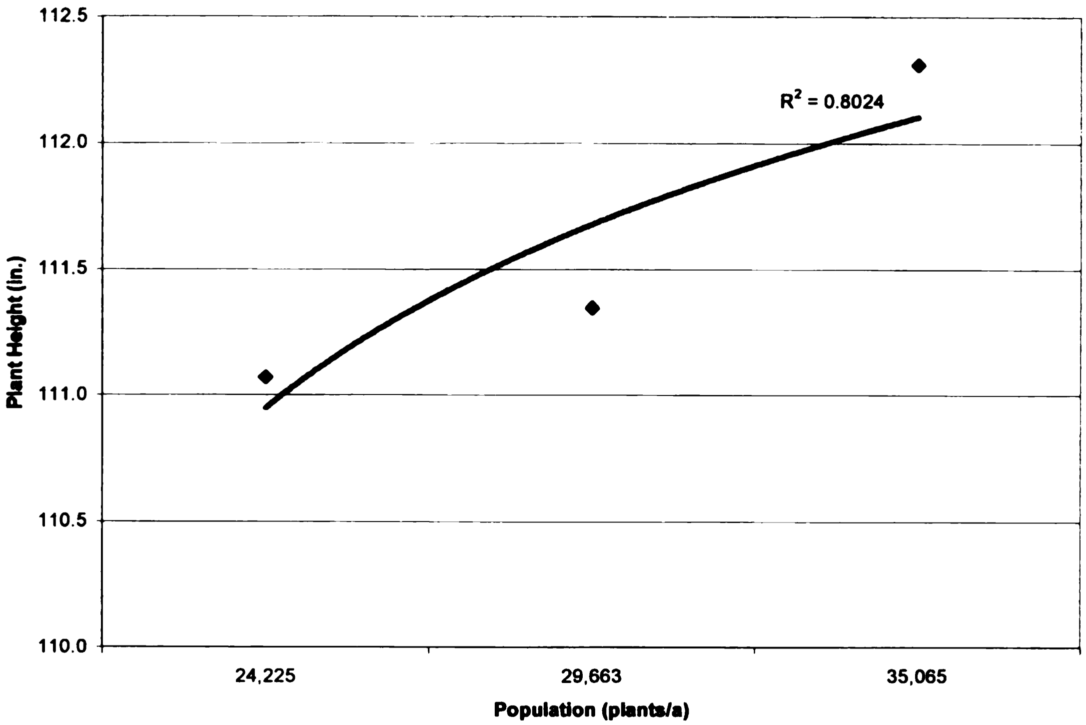

Figure 2.18: Plant height by population averaged over 1998 and 1999. Regression equations for predicting plant height from population is $y = 1.0494\text{Ln}(x) + 110.95$.

Ear Height

The height at which a corn plant sets an ear is correlated with the height of the plant. Like plant height, ear height is also affected by planting date. As the planting date was delayed from April 27th to May 12th, ear height increased from 40.9 inches to 44.9 inches, a difference of 4.0 inches. The rate of increase in height leveled off, and by the May 25th planting, there was only a 0.1 inch increase in ear height over the May 12th planting date (Figure 2.19). Ear height was strongly correlated to the height of the hybrid. The hybrids, listed in order of total plant height, are PIO 3491, Max 8, and DK 493. They had ear heights of 46.1, 43.1, and 41.6 inches, respectively (Figure 2.20). An increase of within row competition, due to an increase in plant population, also caused ear height to increase. When ear height was averaged by plant population there was an increase of 2.2 inches in ear placement as population increased (Figure 2.21).

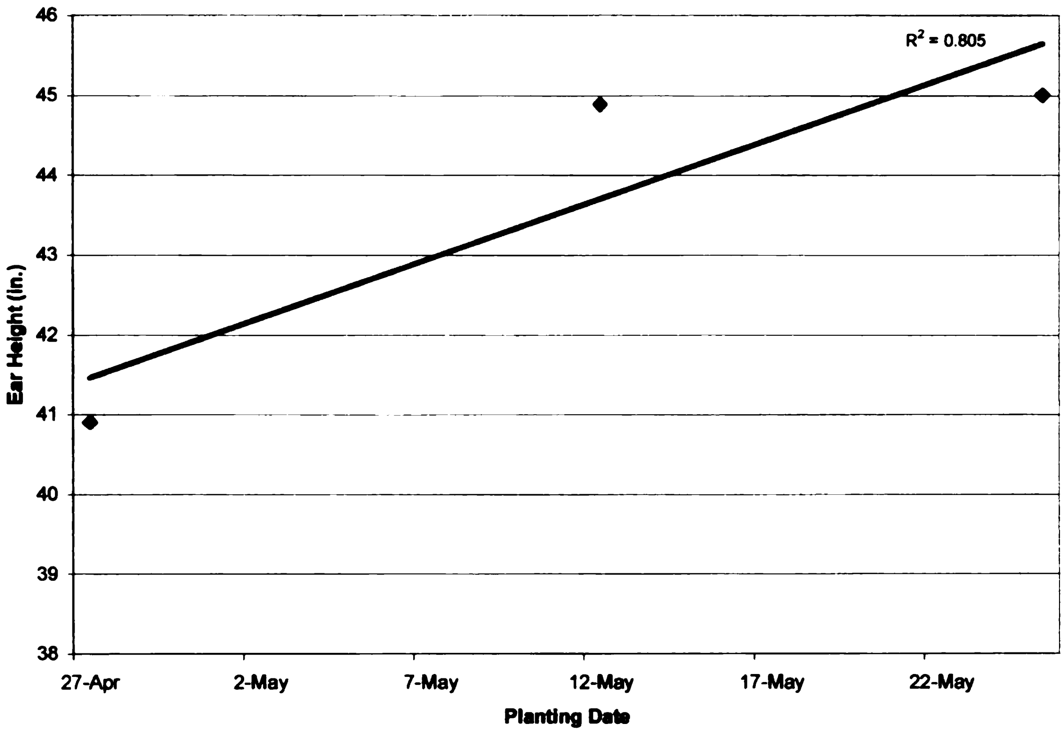

Figure 2.19: Ear height by planting date averaged over 1998 and 1999. Regression equations for predicting ear height from planting date is y = 0.1495x - 5436.7.

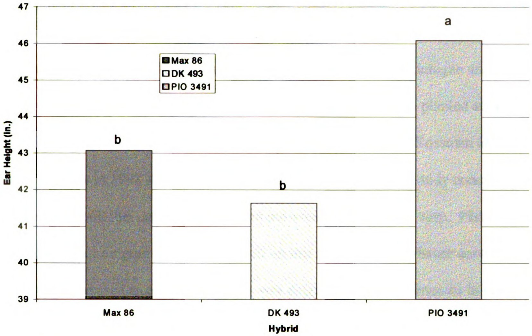

Figure 2.20: Ear height by hybrid averaged over 1998 and 1999. Hybrids are listed in order of maturity. Columns with the same letter are not significantly different.

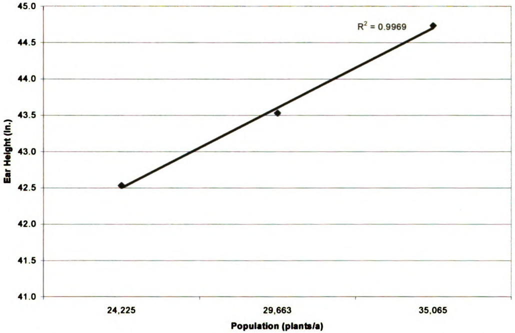

Figure 2.21: Ear height by population averaged over 1998 and 1999. R^2 value included for reference. Regression equation is y = 1.1009x + 41.396.

Conclusion

The importance of planting date has always been a major consideration when planting corn. Rossman and Cook (1966) summarized 14 years of data in Michigan and concluded corn grain yield for early May plantings out-yielded corn planted at later dates. The results of this study are not always consistent with the work of Rossman and Cook. Weather patterns in 1998 favored later planting dates. In 1999 this study concurred with Rossman and Cook that earlier planted corn out-yields later planted corn. Planting date has a large impact on grain moisture. Based on this study, grain moisture content significantly increased as the planting date was delayed. These differences in grain moistures also affected grain test weight, which is an indication of grain quality. Yearly environmental factors affected stalk lodging as planting date was delayed. Plant and ear heights dramatically increased as the planting date was delayed.

The selection of hybrids is crucial for maximum corn grain yields. Hybrids should be selected which will reach physiological maturity for the planting date utilized to reduce drying costs in the fall (Harpstead and Dysinger, 1998). Inherent characteristics of the hybrid should play a major role in hybrid selection. Hybrids that yield well under stress and high plant populations should be selected. Well-adapted hybrids yield equally well under varying row widths and population conditions. Hybrid selection also influences test weight, stalk lodging, as well as plant and ear height.

Row spacing impacted grain yields to a lesser degree than did population and hybrid selection. As row spacing narrowed from 30-inches to 22-, and then to 15-inches, yields increased. Corn grown in narrow row spacing tended to have a yield advantage over corn grown in 30-inch row spacing at earlier planting dates. On average, corn grown in 22-inch rows had a 7.9 bushel per acre increase and corn grown in 15-inch row spacing had an 8.5 bushel per acre increase over the 30-inch rows. Smaller yield advantages were observed in corn grown in narrow rows as planting date was delayed. Row spacing did not affect other traits in the study.

Plant population had the greatest impact on grain yield. As plant population increased, so did grain yield. In 1998, there was a 15.5 bushel per acre increase in yield as plant population increased from 24,000 to 35,000 plants per acre. Yields in 1999 were slightly lower due to environmental conditions resulting in a 10.3 bushel per acre increase from low to high plant populations. As plant population increased, grain moisture decreased by only 0.3%. Never-the-less, this small decrease was statistically significant at the 0.05 level. As plant population increased, stalk lodging also increased by 0.7%. Plant and ear height also increased as plant population increased.

Reference

Benson, G. O. 1990. Corn replant decisions: a review. J. Prod. Agric. 3:180-184.

Dysinger, K., S. M. Canty, J. J. Kells, M. Allen, and D. E. Main. 1997. Corn hybrids compared in the 1997 season. Michigan State University Extension Bulletin E-431.

Fairey, N. A., and T. B. Daynard. 1978. Assimilated distribution and utilization in maize. Can. J. Plant Sci. 58:719-730.

Forcella, Fanck, and Mark E. Westgate, and Dennis D. Warnes. 1992. Effect of row width on herbicide and cultivation requirements in row crops. American J. Altern. Agric. 7:161-167.

Harpstead, D. D., and K. Dysinger. 1998. Relative economic consequences of growing early or late maturing corn hybrids. *In* Proc. 53rd Annu. Corn and Sorghum Res. Conf., Chicago, IL. Am. Seed Trade Assoc., Washington, DC.

Imholte, A. A. and P. R. Carter. 1987. Planting date and tillage effects on corn following corn. Agron. J. 79:-746-751.

Lauer, J. G., P. R. Carter, T. M. Wood, G. Diezel, D. W. Wiersma, R. E. Rand, and M. J. Mlynarek. 1999. Corn hybrid response to planting date in the northern corn belt. Agron. J. 91:834-839.

Loomis, R. S., and W. A. Williams. 1963. Maximum crop productivity: An estimate. Crop Sci. 3:67-72.

Nafziger, E. D. 1994. Corn planting date and plant populations. J. Prod. Agric. 7:59-62.

Palmer, A. F. E., G. H. Heichel, and R. B. Musgrave. 1973. Patterns of translocation, respiratory loss, and redistribution of 14C in maize labeled after flowering. Crop Sci. 13:371-376.

Pendelton, J. W., and D. B. Egli. 1969. Potential yield of corn as influenced by planting date. Agron. J. 61:70-71.

Rossman, E. C., and R. L. Cook. 1966. Soil preparation and date, rate, and pattern of planting. *In* W. H. Pierrce, S. A. Aldrich, and W. P. Maring (eds). Advances in corn production: Principles and practices. Iowa State Univ. Prss.

SAS Institute. 1985. SAS user's guide: Statistics. 5th ed. SAS Inst., Cary, NC.

Staggenborg, S. A., D. L. Fjell, D. L. Devlin, W. B. Gordon, L. D. Maddux, and B. H. Marsh. 1999. Selecting optimum planting dates and plant populations for dryland corn in Kansas. J. Prod. Agric. 12:85-90.

Swanson, Stephan P. and Wallace W. Wilhelm. 1996. Planting date residue rate effects on growth, partitioning, and yield of corn. Agron. J. 88:208-210.

Thomison, P. R. and D. M. Jordan. 1995. Plant population effects on corn hybrids differing in ear growth habit and prolificacy. J. Prod. Agric. 8:394-400.

Tollenaar, M. 1989. Genetic improvements in grain yield of commercial maize hybrids grown in Ontario from 1959 to 1988. Crop Sci. 29:1365-1371.

Tollenaar, M. 1991. Physiological basis of genetic improvement of maize hybrid in Ontairo from 1959 to 1988. Crop Sci. 31:119-124.

Yao, A. Y. M., and R. H. Shaw. 1964. Effect of planting population and planting pattern of corn on the distribution of net radiation. Agron. J. 56:165-169.

CHAPTER 3

EFFECT OF ROW SPACING AND PLANT POPULATION ON CORN SILAGE PRODUCTION IN MICHIGAN

Abstract

Historically, the evaluation of corn hybrids (*Zea mays L.*) for silage production has been performed with dual-purpose hybrids. Dual-purpose hybrids can be used either for corn grain production or for forage production. There have been in recent years, corn hybrids that have been developed with favorable forage production characteristics. Narrow row studies utilizing dual-purpose hybrids have shown that dry matter increases as row spacing narrows (Cox et al., 1998). A two-year narrow row study was initiated at Michigan State University in 1998 utilizing corn hybrids developed specifically for forage production. The object of this study was to determine the effect of row spacing, hybrid type, and plant population on silage quality and yield in Michigan. Four corn hybrids developed specifically for silage production were selected. Each of the four hybrids were planted in 30-, 22-, and 15-inch row spacings. The combination of each hybrid and row spacing was also planted at three plant population levels of 26-, 32-, and 36-thousand plants per acre. The plots were arranged as a split-split-plot design with four replications. There were differences in the quality of the forage harvested between years due to the condition of the plant when the kernel milk line reached the two thirds level. Hybrid, row spacing, and plant population effected dry matter content. Hybrid selection and plant population affected the unadjusted green weight yield in the field. Dry weight yield was affected by the selection of hybrid, row spacing, and plant population. Hybrid

selection and plant population affected harvest index. Hybrid selection, plant population, and the interaction of row spacing and plant population affected dry matter digestibility. Acid detergent fiber and neutral detergent fiber were not affected by row spacing. Hybrid and plant population affected crude protein content. When considering specialty forage hybrids in narrow row systems, hybrid selection, specifically the ability to withstand higher plant populations, is important.

Introduction

Narrow row corn has been gaining interest in recent years. Most of the research on narrow row corn has been to determine the effects on grain yield. A study utilizing dual-purpose hybrids by Cox et al. (1998) in New York found that corn silage yield increased as row spacing narrowed. Row width did not affect silage quality analyses for the three years of his study.

In the past, the evaluation of corn hybrids (*Zea mays L.*) for silage use was conducted on hybrids that were dual-purpose hybrids. Farmers who planted these dual-purpose hybrids could use them for either silage or grain production depending upon the need. In recent years, seed companies have developed hybrids with more favorable silage qualities. These newer hybrids have higher digestibility traits and higher protein content than do the older dual-purpose hybrids.

New hybrids can withstand higher plant population densities than older hybrids (Tollenaar, 1989). Corn silage dry matter increases as plant population levels increase

(Cox, 1996). It is recommended that silage corn be planted at plant population levels 7.5% higher, on average, than corn grain (Cox, 1997). Acid detergent fiber and neutral detergent fiber were not affected by increases in plant population levels (Graybill et al., 1991).

Harvest index is defined as the weight of the grain fraction of the silage divided by the weight of the fodder. A high harvest index indicates a higher grain content in the forage. High grain content makes better ensiling characteristics and increases dry matter and palatability. The harvest index of older hybrids is generally reduced with increases in plant population because of interplant competition reducing the grain portion of the forage (Duncan, 1984). The harvest index of newer released hybrids generally does not decrease as plant population increases (Tollenaar, 1989). The grain content, energy density, and digestibility of maize forage is influenced by the harvest index.

Hybrid selection is key to improving silage quality for optimum animal output. There is significant genetic variability for silage quality between hybrids (Roth et. al., 1970). Acid detergent fiber, neutral detergent fiber, crude protein, and cell wall digestibility are all dependant on the plant genotype (Deinum, 1984).

The objectives of this study were 1) to determine the effects of row spacing on silage yield and silage quality, 2) to evaluate the influence of hybrid type on silage yield response to row spacing, and 3) to document the influence of plant population on silage yield response within row spacings.

Materials and Methods

Field trials were conducted in 1998 and 1999 on a Capac loam soil at the Michigan State University Research Farm in East Lansing, MI. The soil is well drained with a pH of 6.75. Three hundred pounds of urea (0-0-60) per acre and 200 pounds of 6-24-24 per acre were broadcast prior to planting. In both years of the study, soybean preceded corn.

Four maize hybrids BR X6690, PIO 36H36, TMF 106, and TMF 108 with relative maturity ratings of 108, 100, 106, and 108 days, respectively, were used in this study. All hybrids were planted in 30-, 22-, or 15-inch rows. Each row spacing was planted at population levels of 26-, 32-, and 36-thousand plants per acre. Plots were arranged in a randomized complete block design as a split-split plot with four replications. The main plots were represented by hybrids (66 by 30 feet), row spacing was the first split (66 by 10 feet), and plant population represented the split-split plot (22 by 10 feet).

Plant population was determined in all plots after corn emerged. Plots were thinned by hand if the plant population exceeded the established population level for the plot. Plots were harvested with a mechanical, single row, side-mount forage harvester. The middle two rows for the 30-inch plots, the middle three rows for the 22-inch plots, and the middle five rows for the 15-inch plots were harvested as close to the 2/3 milk line stage as possible. Ears from one row of each plot were harvested by hand and weighed to determine the harvest index. (For the purpose of this study the harvest index is defined as the ratio between ear dry matter and fodder dry matter). Sub samples were collected after plot weight was recorded for quality analyses and to determine silage dry matter content.

Silage samples from each plot, containing both fodder and grain, were weighed and oven dried to determine silage dry matter. Separate ear samples and fodder samples were also weighed and oven dried to obtain the harvest index.

Silage samples for quality analyses were ground sequentially through a Wiley mill and Cyclone mill. Dry matter digestibility was obtained by wet chemical analysis from a 0.02 oz. forage sample. In 1998, a wet chemical analysis procedure, using an enzymatic technique outlined by DeBoever (1986), was used to obtain dry matter digestibility. A cellulase solution technique was used to obtain dry matter digestibility in 1999 (Bughrara et al., 1992). Other silage quality components including acid detergent fiber, neutral detergent fiber, and crude protein were determined using near-infra-red spectrometry.

All data was analyzed with the analysis of variance (ANOVA) and the Mixed Linear Model in SAS Statistical Software Package version 6.12 (1989-1996 SAS Institute Inc., Cary, NC,). The Mixed Linear Model is able to calculate the appropriate error terms for statistical tests associated with the split-split plot design. Mean separations were obtained using Tukey's Least Significant Difference Test. To control experimental error, data was blocked by years (Kuehl, 1994). All other variables (hybrid, row spacing, and population) were considered fixed. Regression analysis was used where appropriate. Effects were considered significant in all statistical calculations if P-values <0.05.

Results and Discussion

Remarkably different weather patterns in 1998 and 1999 affected the plots differently. The 1998 growing season had near normal precipitation May through August (Table 3.1). Precipitation for September was markedly lower than the 30-year average. Over all, the 1998 season ended with a precipitation deficit of 1.6 inches compared to the 30-year average. In 1998, growing-degree-day (GDD) accumulation was 144 GDD below normal. Weekly data indicated most of the accumulated GDD for the season occurred during the later part of May, and August through the first part of September. Precipitation fell 3.4 inches below the 30-year average for the 1999-growing season. Timely precipitation (6.8 inches) in July and August increased kernel set at pollination and facilitated kernel fill. This precipitation helped boost yields for the season. Growing degree-day accumulation for the 1999 growing season was near normal.

Table 3.1: Monthly precipitation (inches) and growing-degree-day (GDD) accumulation for the 1998 and 1999 growing seasons. Thirty-year means have been included for comparison (1951-1980).

	Precipitation			Growing Degree Days[1]		
Month	1998	1999	30 yr.	1998	1999	30 yr.
May	2.73	1.78	2.73	442	385	338
Jun	2.51	1.07	3.54	522	474	530
July	2.83	4.75	3.02	618	729	640
August	3.94	2.09	3.12	617	551	598
September	1.29	1.84	2.50	471	424	418
Seasonal Total	13.30	11.53	14.91	2668	2562	2524
DEV[2]	-1.61	-3.38		144	38	

[1] GDD calculated for corn at a base 50^{O}F, with a 50^{O}F and 86^{O}F cutoffs.
[2] The deviation from the 30-year mean.
Data recorded at the Horticultural Research Station, East Lansing, MI.

Favorable field conditions, in both 1998 and 1999, allowed plots to be planted in a timely manner. Plots were planted May 8th and May 4th in 1998 and 1999, respectively. Silage was harvested when the milk line in the kernel was near 65%. In 1998, there was a larger differentiation between hybrid maturities resulting in the longer season hybrids needing more time for the milk line in the kernel to reach 65%. Consequently, harvest was prolonged over a longer period. Harvesting occurred between August 24th and August 31st in 1998. In 1999, harvest occurred on September 3rd due to the degree day compression of the hybrids.

Statistical analyses were combined for the 1998 and 1999 growing seasons. The summary of the ANOVA table for silage yield shows the significance of the main effects of hybrids, row spacing, population, and their interactions for dry matter, green weight per acre, dry weight per acre, and harvest index (Table 3.2). The summary of the ANOVA table for the silage quality components shows the significance of the main effects and the respective interactions for dry matter digestibility, acid detergent fiber,

Table 3.2: Summary of combined analysis of variance for dry matter (%DM), green weight per acre (Gwt/A), dry weight per acre (Dwt/A), and harvest index (HI) for 1998 and 1999.

Source of variation	%DM	Gwt/A	Dwt/A	HI
	P-values from ANOVA[1]			
Year	0.0001	0.0002	0.0001	0.0001
Hybrid	0.0001	0.0733	0.0001	0.0038
Row Spacing	0.0322	0.1887	0.0005	0.3903
Hyb*Row	0.3963	0.0072	0.0006	0.4254
Population	0.0121	0.0001	0.0001	0.6355
Hyb*Pop	0.9850	0.0639	0.1322	0.0010
Row *Pop	0.5896	0.2592	0.0703	0.8472
Hyb*Row*Pop	0.2750	0.9764	0.6739	0.2239

[1] Probability P=0.05

neutral detergent fiber, and crude protein (Table 3.3). Years were significant for all traits measured due to physiological maturity differences between corn harvest at two-thirds milk line. The hybrid main effect showed significant differences for all traits measured in this experiment, except for green weight per acre. Row width was found to affect dry matter and dry weight per acre. The two-way interaction between hybrid and row spacing was significant for green weight per acre and dry weight per acre. Plant population was significant for all traits, except for harvest index. Harvest index was significantly affected by the two-way interaction of the main effects of hybrid and plant population. Dry matter digestibility was also affected by a two-way interaction of row spacing and plant population.

Table 3.3: Summary of combined analysis of variance for dry matter digestibility (%DMD), acid detergent fiber (%ADF), neutral detergent fiber (%NDF), and crude protein (% CP) for 1998 and 1999.

Source of variation	%DMD	%ADF	%NDF	%CP
	P-values from ANOVA[1]			
Year	0.0001	0.0001	0.0024	0.0007
Hybrid	0.0001	0.0001	0.0004	0.0043
Row Spacing	0.8001	0.2547	0.6904	0.7804
Hyb*Row	0.9841	0.6395	0.6318	0.5582
Population	0.0298	0.0021	0.0068	0.0001
Hyb*Pop	0.6963	0.5901	0.3769	0.7492
Row *Pop	0.0111	0.4945	0.2127	0.5539
Hyb*Row*Pop	0.8415	0.8576	0.5903	0.1889

[1] Probability P=0.05

Percent Dry Matter

The differences in silage dry matter (%DM) between years were significant (Figure 3.1). These differences were caused by variations in physiological maturity of the corn from 1998 and 1999. Silage harvested in 1998 averaged 32.6% DM, while the average for 1999 was 40.3% DM. This difference in DM was caused by the variation in plant health when the milk line in the kernel reached two-thirds. Because of these differences in DM, all other variables in this study were affected.

There were also differences between hybrids and the percent dry matter. There was a strong correlation between hybrid maturity and dry matter content (Figure 3.1). The later maturing hybrids had the highest percent dry matter, while the shorter season hybrids had the lowest.

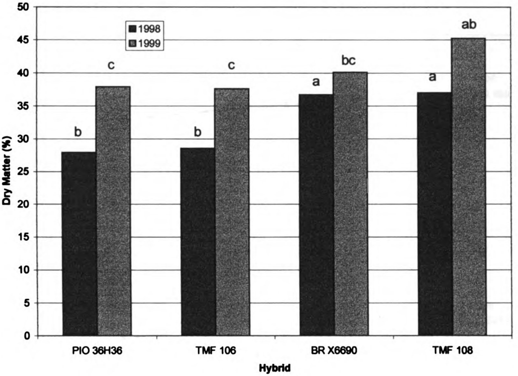

Figure 3.1: Dry matter by hybrid and year. Hybrids are listed in order of maturity. Columns within a year followed by the same letter are not significantly different.

As row spacing narrowed, the percent dry matter increased (Figure 3.2). Dry matter increased by 1.1 and 0.9% in 1998 and 1999, respectively, as row spacing was narrowed from 30-inches to 15-inches.

As plant population increased, dry matter content dropped 0.6% in 1998 due to stress associated with lack of moisture (Figure 3.3). This trend was reversed in 1999 when dry matter content increased by 2.9% as plant population increased. There was also a difference in dry matter between row spacing by years. In 1998, the dry matter content averaged 32.6%, and in 1999, the average dry matter content was 39.7%.

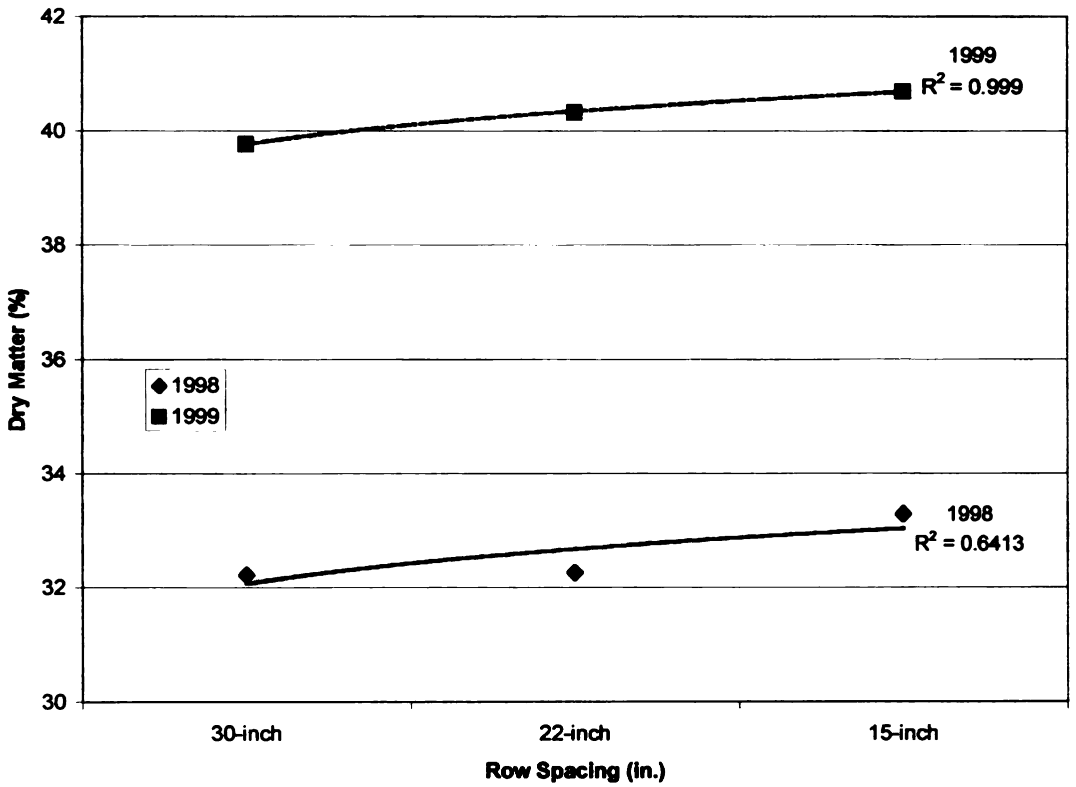

Figure 3.2: Dry matter by row spacing and year. Regression equations for predicting dry matter from row spacings by years are:
1998 - $y = 0.8738Ln(x) + 32.074$
1999 - $y = 0.8323Ln(x) + 39.763$

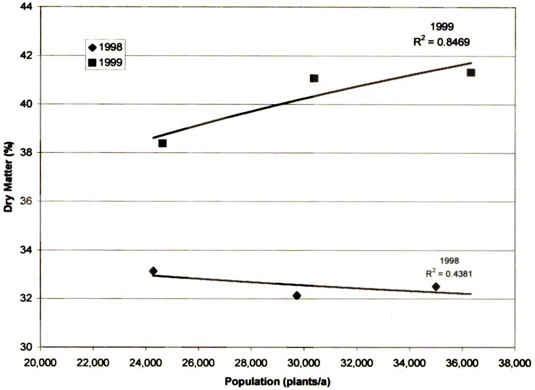

Figure 3.3: Dry matter by population and year. Regression equations for predicting dry matter from population by year are:
1998 - $y = 7.7114Ln(x) - 39.254$
1999 - $y = -1.8455Ln(x) + 51.58$

Green Weight (Tons/Acre)

Silage green weight was affected by a two-way interaction of hybrid by row spacing (Figure 3.4). As row spacing was narrowed to less than 30-inches, green weight increased for all hybrids. All hybrids, except for TMF 106, had an increase in green weight for 22-inch rows. The 15-inch rows had higher green weight yield across hybrids, except BR X6690, where the green weight yield was lower than for the 30-inch row spacing.

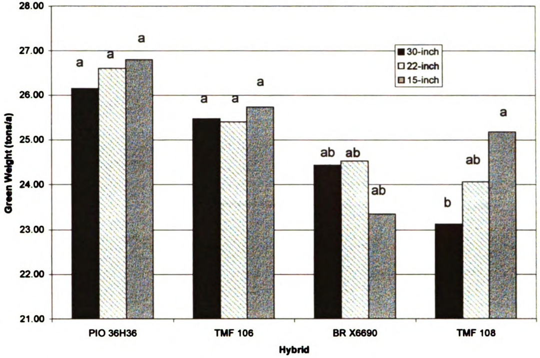

Figure 3.4: Green weight by hybrid and row spacing. Hybrids are listed in order of maturity. Columns followed by the same letter are not significantly different.

Green weight response to plant population was markedly different between years. In 1998, green weight yield increased 2.9 ton per acre from the lowest to highest plant population (Figure 3.5). In 1999, there was a drop in green weight of 0.2 ton per acre as plant population increased. In 1998, the average green weight was 26.7 ton per acre. The average for 1999 was 23.4 ton per acre when averaged across plant population. This difference in green weight may be due to the lower precipitation totals for 1999 prior to silage harvest.

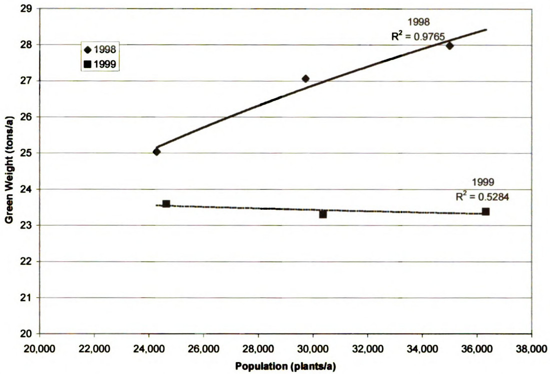

Figure 3.5: Green weight by population and year. Regression equations for predicting green weight from population by year are:
1998 - y = 8.1308Ln(x) - 56.94
1999 - y = -0.5664Ln(x) + 29.268

Dry Weight (Tons/Acre)

Silage dry weight yield differences between years were significant (Figure 3.6). The dry weight yield averages for 1998 and 1999 were 8.6 ton per acre and 9.3 ton per acre, respectively. The dry weight yield was different among hybrids. The shorter season hybrids yielded less dry matter per acre than did the later maturing hybrids. This trend between hybrids was evident both years of the study.

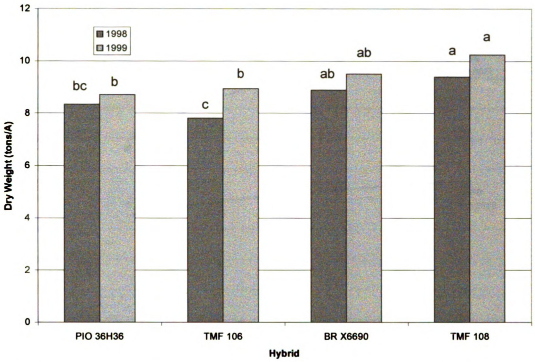

Figure 3.6: Dry weight by hybrid and year. Hybrids are listed in order of maturity. Columns with the same year followed by the same letter are not significantly different.

Silage dry weight yield increased as row spacing was narrowed from 30-inches to 15-inches. Differences in dry weight yield by row spacing was also observed between years (Figure 3.7). The silage dry weight yield averaged over row spacing was 8.6 ton per acre and 9.4 ton per acre for 1998 and 1999, respectively. In 1998, silage dry weight increased 0.2 ton per acre from 30-inch rows to 15-inch rows. There was a 0.1 ton per acre drop in silage dry weight for the same year when row spacing was narrowed from 30-inches to 22-inches. There was a 0.6 ton per acre increase in 1999 as row spacing was narrowed from 30-inch to 15-inch row spacing.

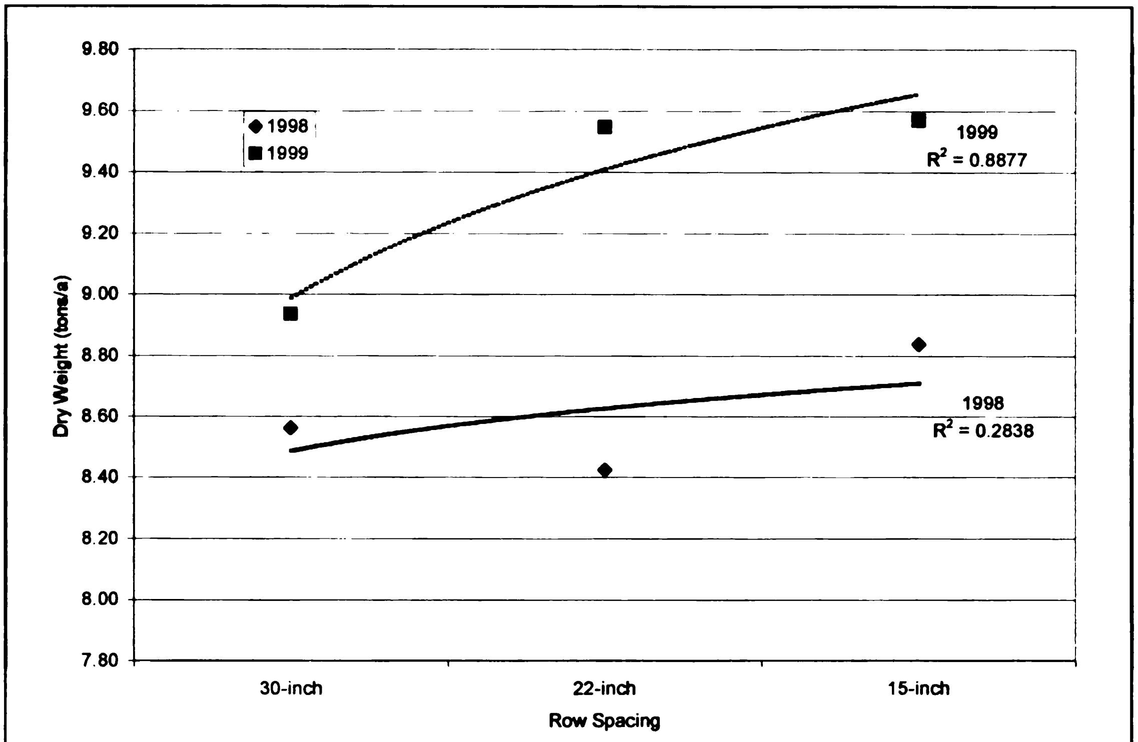

Figure 3.7: Dry weight by row spacing and year. Regression equations for predicting dry weight from row spacing by year are:
1998 - $y = 0.2019Ln(x) + 8.4873$
1999 - $y = 0.6092Ln(x) + 8.9861$

There was a hybrid by row spacing interaction that affected silage dry weight yield. Most of the hybrids had an increase in dry weight yield as row spacing was narrowed from 30-inches (Figure 3.8). Two of the hybrids showed inconsistencies in yields for the 22-inch row spacing. The 22-inch row spacing yielded 0.2 ton per acre less than the 30-inch rows for TMF106 when averaged over the two years of the study. There was a 0.5 ton per acre increase of the 22-inch row spacing over the 15-inch row spacing for BR X6690. The largest increase in dry weight for narrow rows occurred with the TMF 108 hybrid. There was a 1.2 and a 0.6 ton per acre dry weight yield increase for 22- and 15-inch row spacings, respectively, over the 30-inch row spacing.

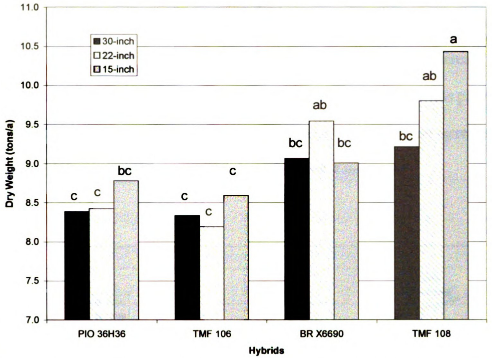

Figure 3.8: Dry weight by hybrids and row spacing. Hybrids are listed in order of maturity. Columns followed by the same letter are not significantly different.

Silage dry weight yield differed over years when averaged across plant population. In 1998, the average silage dry weight yield was 8.6 ton per acre when yield was averaged across plant population (Figure 3.9), and there was a 0.8 ton per acre increase in silage dry weight as plant population was increased from lowest to highest. As plant population increased from lowest to highest in 1999, there was a 0.6 ton per acre increase in dry weight and the average silage dry weight yield was 9.4 ton per acre.

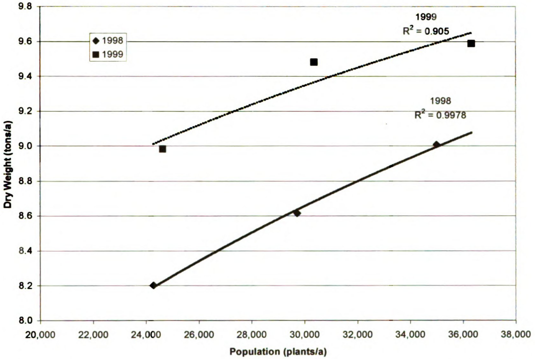

Figure 3.9: Dry weight by population and year. Regression equations for predicting dry weight from population by year are:
1998 - y = 2.2009Ln(x) - 14.032
1999 - y = 1.5852Ln(x) - 6.9954

Harvest Index

Harvest index, the percentage of corn grain in the forage mix, is a good indicator of the energy available in silage. There were differences between years when harvest index was averaged over hybrids (Figure 3.10). The harvest index in 1998 was the lowest, averaging 50.6%. In 1999, the harvest index was 55.8% of corn grain in the total silage mix. Hybrids exhibited different harvest indices. Hybrid TMF 106 produced the lowest harvest index (46%) by any hybrid in 1998. The highest harvest index, 57.4%, was produced by PIO 36H36 in 1999. The most consistent harvest index was produced by TMF 108. It had a harvest index of 50.6% and 53.4% for 1998 and 1999, respectively.

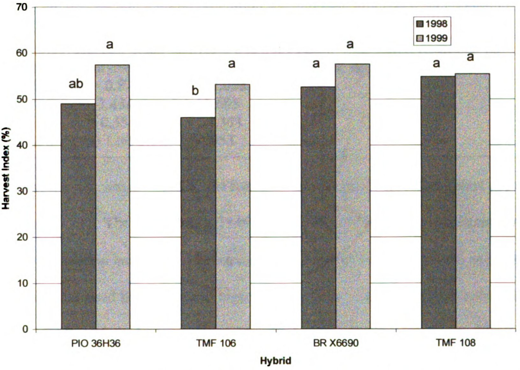

Figure 3.10: Harvest index by hybrid and years. Hybrids are listed in order maturity. Columns within a year followed by the same letter are not significantly different.

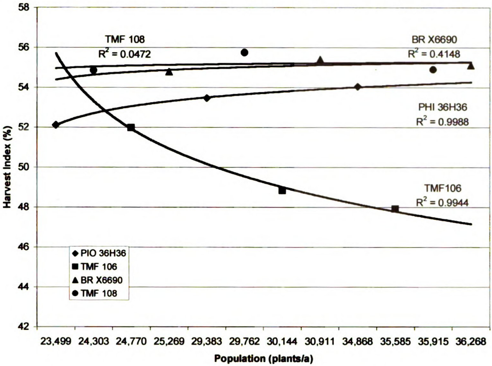

Figure 3.11: Harvest index by hybrid and population. Regression equations for predicting the harvest index from population by hybrid are:
PIO 36H36 - y = 0.8721Ln(x) + 52.098
TMF 106 - y = -3.4347Ln(x) + 55.695
BR X6690 - y = 0.3548Ln(x) + 54.383
TMF 108 - y = 0.1269Ln(x) + 54.953

The harvest index was affected by the two-way interaction of hybrid and plant population (see Figure 3.11). The two hybrids, TMF 108 and BR X6690, held a consistent harvest index as population increased. The harvest index increased for PIO 36H36 as plant population increased from lowest to highest. There was a significant drop in harvest index for TMF 106 as plant population increased. The harvest index dropped from 58% to 48% as plant population was increased from lowest to highest. The interaction between plant population and harvest index may be correlated with a hybrid's ability to withstand high plant population stress.

Dry Matter Digestibility

There were differences in hybrid dry matter digestibility between years. The average digestibility of the hybrids, when averaged over years, was 67.6% and 62% for 1998 and 1999, respectively (Figure 3.12). Dry matter digestibility of the hybrids was lower in 1999 than in 1998. This difference in digestibility was due to differences in hybrid physiological maturity at which hybrids were harvested each year. The same hybrid, TMF 106, had the lowest digestibility both years of the study. The hybrid with the highest digestibility for both years of the study was BR X6690.

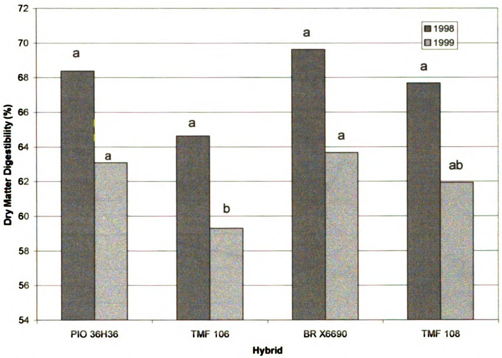

Figure 3.12: Dry matter digestibility by hybrids and years. Hybrids listed in order of. Columns within a year followed by the same letter are not significantly different.

Plant population affected silage dry matter digestibility. As plant population increased, silage dry matter digestibility decreased (Figure 3.13). In 1998, when silage dry matter digestibility was averaged over plant population, it averaged 67.6%. The dry matter digestibility dropped only 0.4% in 1998 as plant population increased from lowest to highest. In 1999, dry matter digestibility decreased 1.7% as plant population was increased from lowest to the highest. The average silage dry matter digestibility, for the 1999-growing season, was 62%.

Silage dry matter digestibility was affected by the interaction of hybrid and row spacing. Silage from corn grown in narrow row widths had higher dry matter digestibility than did

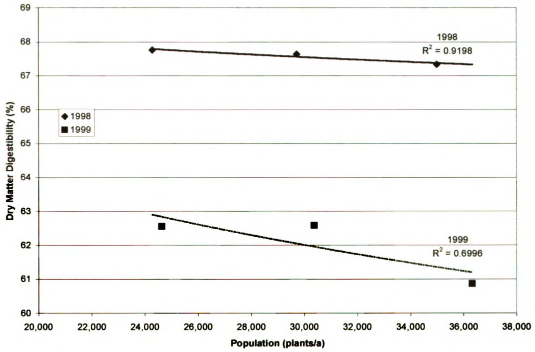

Figure 3.13: Dry matter digestibility by population and years. Regression equations for predicting dry matter from population by year are:
1998 - $y = -1.1386Ln(x) + 79.287$
1999 - $y = -4.235Ln(x) + 105.66$

the 30-inch row. The 22-inch row spacing had higher DMD the 15-inch row spacing at the lower two population levels of 24,460 and 30,050 plants per acre. The 22-inch row spacing had a 3% decrease in dry matter digestibility from the 30-inch row spacing, while the 15-inch row spacing had a 0.3% increase over the 30-inch rows (Figure 3.14).

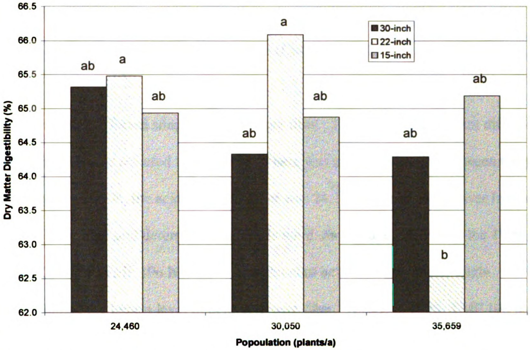

Figure 3.14: Dry matter digestibility by population and row spacing. Columns followed by the same letter are not significantly different.

Acid Detergent Fiber

Acid detergent fiber contains cellulose, lignin, and heat-damaged protein. It is the fraction insoluble in an acid detergent solution. Acid detergent fiber is closely related to the digestibility of the forage. The relationship between acid detergent fiber and digestibility is an inverse relationship in that, as acid detergent fiber decreases, the potential digestibility of the forage increases (Cullison, 1982).

Hybrid selection affected silage acid detergent fiber. There was a significant difference between the hybrids selected for this trial. There was also a difference between the years of the study. In 1998, the acid detergent fiber was 24.1% when averaged over hybrids (Figure 3.15). The acid detergent fiber levels were, on average, 28.8% for the 1999 season. In 1998, TMF 106 had the highest level of acid detergent fiber, while BR X6690 had the lowest level of acid detergent fiber. Again, in 1999, TMF 106 had the highest level of acid detergent fiber but PIO 35H36 had the lowest level.

As plant population increased from lowest to highest, the percentage of acid detergent fiber increased. In 1998, acid detergent fiber increased 0.4% when plant populations increased (Figure 3.16). There was a 1.7% increase in acid detergent fiber level as plant population increased in 1999. On average, acid detergent fiber levels were 24.0% and 28.3% for 1998 and 1999, respectively.

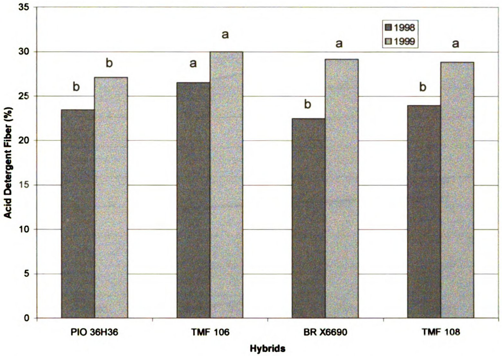

Figure 3.15: Acid detergent fiber by hybrid and year. Hybrids are listed in order of maturity. Columns followed by the same letter are not significantly different.

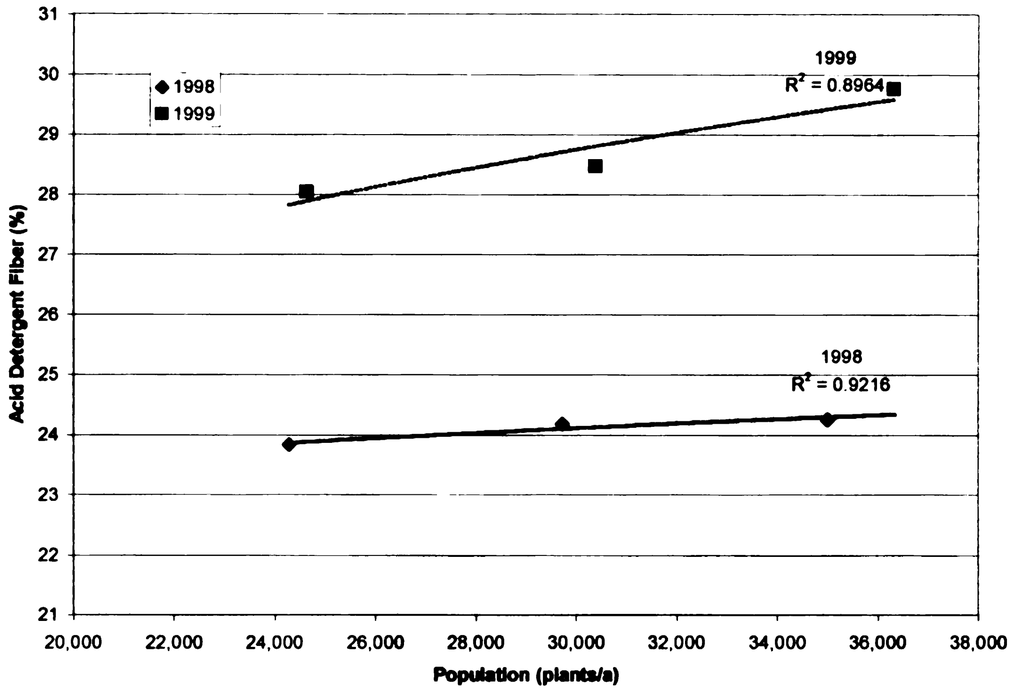

Figure 3.16: Acid detergent fiber by population and years. Regression equations for predicting acid detergent fiber from population by year are:
1998 - y = 1.1852Ln(x) + 11.9
1999 - y = 4.3765Ln(x) - 16.369

Neutral Detergent Fiber

Neutral detergent fiber is the percentage of cell wall material or plant structural components in forage. The total fiber content of forages is contained in the neutral detergent fiber fraction. The neutral detergent fiber contains cellulose, hemicellulose, lignin, and heat -damaged protein. Neutral detergent fiber is inversely related to the intake potential of the forage (Cullison, 1982).

Corn silage neutral detergent fiber was affected by hybrid selection. There were also differences between years for each hybrid selected for this study. The average neutral detergent fiber across all hybrids for 1998 and 1999 was 43.5% and 46.3%, respectively (Figure 3.17). The neutral detergent fiber levels for TMF 106 were the highest for both years of the study. The lowest percent of silage neutral detergent fiber were for BR X6690, in 1998 and PIO 36H36 in 1999.

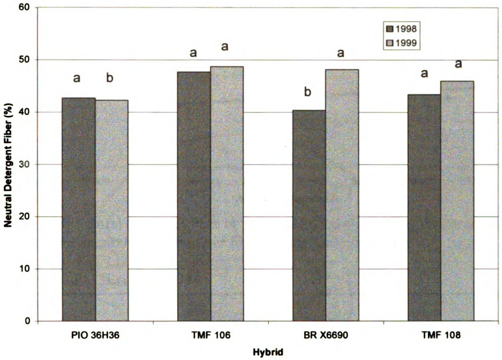

Figure 3.17: Neutral detergent fibers by hybrids and years. Hybrids are listed in order of maturity. Columns followed by the same letter are not significantly different.

Silage neutral detergent fiber increased as plant population increased. In 1998, neutral detergent fiber averaged across plant population was 43.5% and increased 0.3% as plant population increased (Figure 3.18). There was a 2.7% increase in neutral detergent fiber in 1999, as plant population increased. The average neutral detergent fiber level, when averaged across all populations for 1999, was 45.5%.

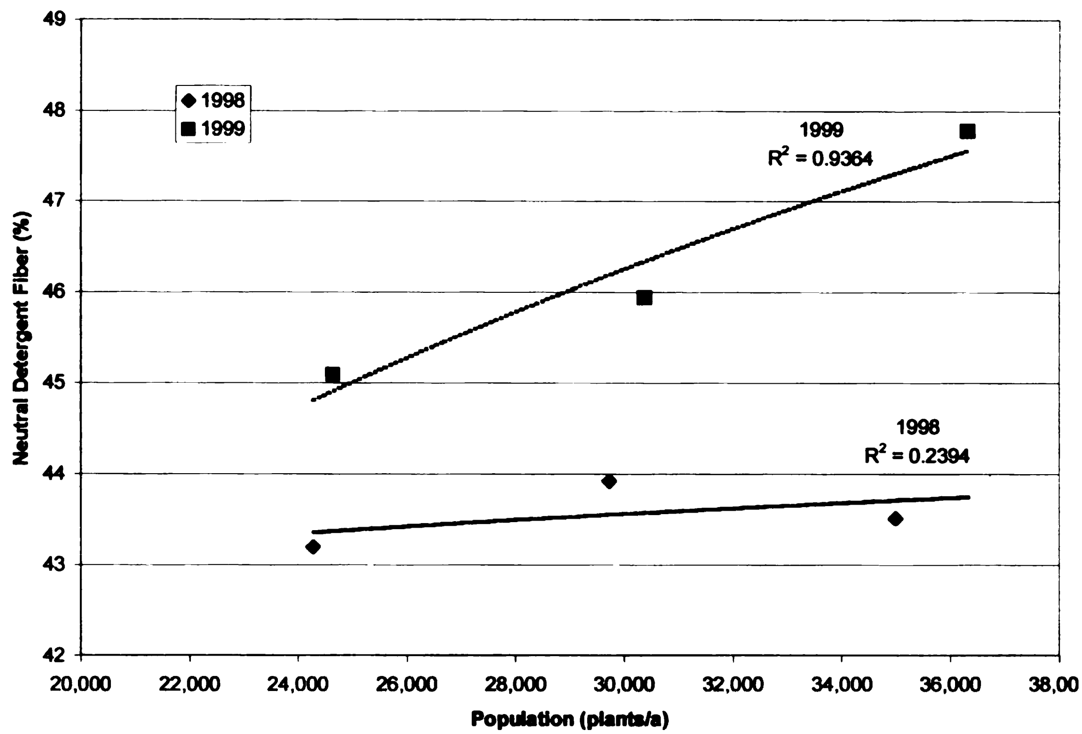

Figure 3.18: Neutral detergent fiber by population and years. Regression equations for predicting neutral detergent fiber from population by year are:
1998 - $y = 0.9732Ln(x) + 33.528$
1999 - $y = 6.8533Ln(x) - 24.396$

Crude Protein

Silage crude protein was affected by the inherent characteristics of the hybrids. There were significant differences in silage crude protein levels from year to year. In 1998, the average protein level was 7.1%, and in 1999 it was 7.7% (Figure 3.19). PIO 36H36 had the most consistent levels of crude protein between the two years of the study. In 1998, PIO 36H36 had the highest level of crude protein at 7.8% and the second highest level of crude protein in 1999 at 7.9%. The highest level of crude protein in 1999 was BR X6690 at 8.1%.

Plant population affected silage crude protein. As plant population increased, silage crude protein decreased. In 1998, crude protein levels decreased 0.2% as plant population increased from lowest to highest (Figure 3.20). There was a 0.5% drop in silage crude protein in 1999, as plant population increased. The average crude protein for 1998 and 1999 was 7.1% and 7.9%, respectively.

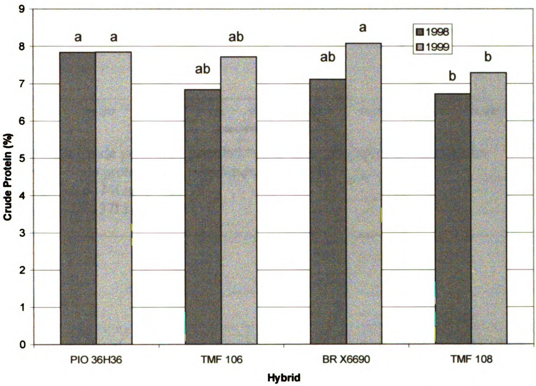

Figure 3.19: Crude protein by hybrid and year. Hybrids are listed in order of maturity. Columns followed by the same letter are not significantly different.

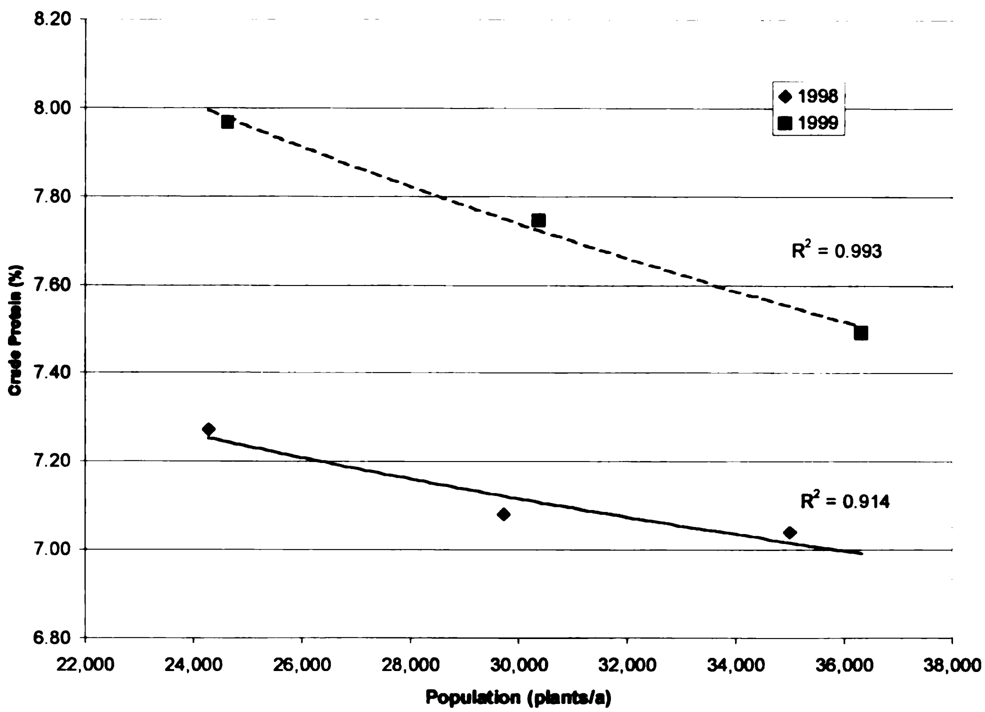

Figure 3.20: Crude protein by population and year. Regression equations for predicting crude protein from population by year are:
1998 - $y = -0.6474\mathrm{Ln}(x) + 13.79$
1999 - $y = -1.2137\mathrm{Ln}(x) + 20.251$

Conclusion

The physiological maturity of corn hybrids is critical when harvesting corn for silage. The quality of corn silage is dependent upon the stage at which the corn is harvested. This can be observed in the difference between the silage quality traits over the two years of this study. In 1998, silage was harvested at earlier physiological maturity than in 1999. As corn advances in maturity, dry matter increases within the plant. Subsequently, tissues within the plant contain less water and more components that are harder to digest. This increase in lignin, cellulose, and hemicellulose decreases the dry matter digestibility of the silage. This, in turn, affects the acid detergent fiber and the neutral detergent fiber.

The only silage component that increases as corn matures is crude protein. Crude protein increases as the grain in the silage matures and ripens. As harvest is delayed, the increase in dry matter affects the green weight yield, resulting in less total tonnage per acre.

The inherent characteristic of hybrids selected for corn silage appears to have a significant impact on many aspects of corn silage, with the exception of green weight per acre. Plant architecture will affect the yield. Plants that are taller tend to produce more tonnage per acre than do shorter plants at the same population. The genetic characteristics of the plant tend to affect the digestibility of the silage as well as the potential intake. The harvest index on a hybrid is a good indication of how a hybrid responds to stress. If the harvest index does not decrease as plant population increases the hybrid is able to withstand stress well. The harvest index is also closely related to the crude protein in the silage.

Row spacing affected the dry matter content of the corn silage. Corn grown in narrow rows tended to be drier than corn grown in wide rows. Narrow rows will also promote more plant growth than wider rows. Corn grown in narrow rows tended to be taller, thus producing more tonnage per acre. Row spacing affected green weight yield and the dry weight yield (tons per acre).

Plant population affected all aspects of silage production and quality, except for the harvest index. As one would expect, as the number of plants per acre increase, so does the tonnage produced per acre. The amount of silage dry matter also increases. Stresses associated with the higher plant population may reduce the digestibility of the silage. The interaction between hybrids and plant population also affects the harvest index that is produced. Dry matter digestibility is affected by the interaction of row spacing and population.

References

Bughrara, S. S. and D. A. Sleper, 1986. Digestion of several tempaerate forage species by a prepared cellulase solution. Agron. J. 84:94-98.

Bughrara, S. S., D. A. Sleper, and P. R. Beuselinck, 1992. Comparison of cellulase solutions for use in digesting forage samples. Aron. J. 14:203-214.

Cox, William J., 1996. Whole-plant physiological and yield response of maize to plant density. Agron. J. 88:489-496.

Cox, William J. 1997. Corn silage and grain yield response to plant densities. J. Prod. Agric. 10:405-410.

Cox, William J., Debbie R. Cherney, and John J. Hanchar. 1998. Row Spacing, hybrid, and plant density effects on corn silage yield and quality. J. Prod. Agric., 11:128-134.

Cullison, Arthur, 1982. Feeds and Feeding third edition. Reston Publishing Co. Inc., Reston VI.

De Boever, J. L., B. G. Cottyn, F. X. Buysse, F. W. Wainman, and J. M. Vanacker, 1986. The use of an enzymatic technique to predict digestibility, metabolism and net energy of compound feed stuffs for ruminants. Anim. Feed Sci. Technol., 14:203-214.

Deinum, W. G. 1984. A theory to explain the relationship between corn population and grain yield. Agron. J. 24:1141-1145.

Duncan, W. G., 1984. A theory to explain the relationship between corn population and grain yield. Agron. J. 24:1141-1145

Graybill, J. S., W. J. Cox, and D. J. Otis. 1991. Yield and quality of forage maize as influenced by hybrid, planting date and plant population. Agron. J. 83:559-564.

Kuehl, Robert O. 1994. Complete Block Designs. *In* Statistical Principles of Research Design and Analysis. Duxbury Press.

Roth, L. S., G. C. Marten, W. A. Compton, and D. D. Stuthman, 1970. Genetic variation of quality traits in maize (zea mays L.) forage. Crop Science 10:365-367.

SAS Institute. 1985. SAS user's guide: Statistics. 5th ed. SAS Inst., Cary, NC.

Tollenaar, M. 1989. Genetic improvement in grain yield of commercial maize hybrids grow in Ontario from 1959 to 1988. Crop Sci. 29:1365-1371.

CHAPTER 4

EFFECT OF ROW SPACING AND PLANT POPULATION ON TRANSGENIC *Bt* CORN PERFORMANCE IN MICHIGAN

Abstract

European Corn Borer (*Ostrinia nubilalis*) is a significant pest in the corn growing area of North America. In the predominant corn growing areas European Corn Borers (ECB) will produce two generations of offspring per season. The feeding damage of ECB can result, on average, in a 16 bushel per acre yield loss (Rice, 1997). Seed corn companies have developed ECB resistant hybrids that produce a toxin that kills ECB upon ingestion of plant material. This toxin is produced from a *Bacilllus thuringensis* (B*t*) gene that is inserted into the corn genome. A two year study was conducted at Michigan State University in 1998 and 1999 to determine whether corn hybrids containing the B*t* gene are better suited for narrow row corn production systems than conventional hybrids. Three near-isogenic hybrids were selected for this study. One of the three hybrids was a conventional hybrid without any transgenic genes. The other two hybrids contained one additional gene of Cry1Ab or Cry1Ac each. Each of the three hybrids were planted at three row spacings of 30-, 22-, and 15-inch rows. Each row spacing and hybrid combination was planted at three plant populations. The plots were arranged in a split-split-plot design. The effect of ECB pressure could not be assessed due to weather conditions that did not favor ECB infestation. As expected, hybrid type did not have an affect on grain yield due to the fact that the hybrids were near-isogenic. There was an increase in grain yield as plant population increased. The 15-inch row spacing had an

average of 8.7 bushel per acre yield advantage over the 30-inch row spacing. Only plant population affected grain moisture. Large differences in test weight were affected by the growing condition from year to year and by row spacing. Differences in stalk lodging were observed between years and row spacings. These results indicate that genetically engineered hybrids yield equally well in narrow row systems which utilize higher populations.

Introduction

The European Corn Borer (ECB), *Ostrinia nubilalis,* is a devastating insect pest in the corn growing regions of North America and Europe (Beck, 1987; Hudon et al., 1987). Throughout the North American Corn Belt, two generations of ECB are typical. The first generation ECB causes damage by feeding on the whorl leaf and tassel, as well as stalk tunneling. The second generation attacks the tassel, silks, and ear shanks. Yield losses are caused by reduced plant growth, stalk lodging, dropped ears, and poor grain quality. In Iowa, during the five years between 1991 and 1996, yield losses, on an average, were 16 bushels per acre due to ECB (Rice, 1997).

In recent years, much publicity has been generated about ECB-resistant corn. This resistance is achieved by inserting a gene from the soil bacterium *Bacillus thuringiensis* (*Bt*) into the corn plant. The *Bt* gene produces a crystal protein that is toxic to insects. There are over 3,000 strains of the *Bt* organism that have been identified and each produces a different protein that is toxic to certain target insects (Feitelson et al., 1996). The crystal protein, which is produced to provide resistance from ECB, is from the strain

B.t. kustaki. This protein is deadly only to Lepidoptera larvae when ingested. Once the protein is ingested, the crystal protein binds to the midgut of the ECB. The binding of the crystal protein causes the gut to rupture or leak. This process stops the ECB from feeding and it may or may not cause it to die.

The genes that produce this crystal protein are either the Cry1Ab or Cry1Ac gene. The Cry1Ab gene has been inserted into plants three different times and each insertion is known as an event. These different events, utilizing the Cry1Ab, have become known as 176, Bt-11, and MON-810. The Cry1Ac event is known as the DBT 418. Each event expresses the crystal protein in the plant differently and for a different duration. Events MON-810 and Bt-11 provide 99% control of first and second generation ECB. Events 176 and DBT 481 provide 99% control of first generation ECB, but only control 50-75% of second generation ECB.

Differences in the expression of the Cry1Ab gene are due to the location of gene insertion into the corn chromosome. This point of insertion could potentially interfere with the yield of the hybrid. Some have suggested there might be a "yield drag" associated with ECB-resistant corn, similar to that seen in Imidazolinone-resistant corn hybrids (Kells and Dysinger, 1996).

ECB-resistant corn hybrids grown in the absence of ECB pressure, may yield less than other new corn hybrids. (Hayenga et al., 1992). This difference in yield may be due to the time lag it takes to backcross transgenic traits into the inbred parents of the existing hybrid (Greaves et al., 1993). The backcrossing technique requires four to seven generations to transform the trait into the recurrent inbred and recovers 99% of the recurrent inbred's genetic background (Greaves et al., 1993; Newhouse et al., 1991a). In addition, the transgenic inbreds might take up to three years of testing to ensure that near-isogenic inbreds have been recovered (Newhouse et al., 1991a). The time required to backcross the transgenic trait into an inbred will cause a transgenic hybrid to lag behind the yield advantage of new hybrids, which have expected yield increases of 1-2% per year (Hallauer et al., 1988).

Hybrids transformed with the *Bt* genes are available and are being highly marketed by seed companies. Michigan growers need to know how these hybrids compare to non-transgenic hybrids under environmental conditions within the state. Growers should be informed about their options and how these corn hybrids perform for them. In the past, transgenic hybrids yielded less than their non-transgenic, near-isogenic counterparts when compared under low ECB pressure. Recent data, however, shows the transgenic, near-isogenic hybrids are improving and may yield more than non-transgenic, near-isogenic hybrids. Nevertheless, the question remains whether transgenic hybrids respond similarly to row spacing and population across different *Bt* events.

Methods and Materials

Field studies were conducted in southern Michigan in 1998 and 1999. Trial locations in Calhoun and Monroe counties were chosen to ensure sufficient levels of ECB infestation. Three near-isogenic hybrids were selected for this study. Two of the three hybrids, DK

580BtX and DK 580BtY, were genetically modified for resistance to corn borer using Cry1Ab or Cry1Ac gene, respectively. The hybrid DK 580 was selected as the non-transgenic hybrid for comparison. The three hybrids were planted in 30-, 22- and 15-inch row spacings. Each of the row spacings were planted at population levels of 26-, 32-, and 38-thousand plants per acre.

The trials were arranged as a split-split-plot design with a complete block randomization and four replications. The whole plot was represented by the hybrids (66 by 30 feet), row spacing represented the split-plot (66 by 10 feet), and the population (22 by 10 feet) represented the split-split plot. This design was chosen so main effects and their interactions could be better observed.

Plots were planted with a mechanical planter capable of planting in 30, 22, and 15 inch row widths. After plants emerged, stand counts were taken on all plots to determine the population. Plots were thinned by hand if population levels exceeded levels assigned to the particular plot.

At planting time, an additional 10-foot plot was planted at the end of each plot to assess ECB population levels. Five consecutive corn plants were selected, prior to harvest, from each plot to determine the amount of plant injury from natural infestation of corn borer. These five corn plants were dissected to assess the number of ECB larvae per plant, and the length of tunneling.

Lodging notes were taken prior to corn grain harvest. Only plants with stalks broken below the ear were counted as lodged. The percent of lodging was calculated based upon the total number of plants in the plot.

Plots were harvested mechanically for corn grain. Moisture content and field weights were automatically measured by the GrainGage™, a HarvestData System™ mounted on the plot combine. This system used the grain samples from each plot and sped up the harvesting and data collection procedure. Grain yields were reported at a standard 15.5% moisture. Test weights were recorded and reported at harvest moisture.

All data was analyzed with the analysis of variance (ANOVA) and the Mixed Linear Model in SAS Statistical Software Package version 6.12 (1989-1996 SAS Institute Inc., Cary, NC,). The Mixed Linear Model is able to calculate the appropriate error terms for tests associated with the split-split-split plot design. Mean separations between all variables were obtained by Tukey's Least Significant Difference Test. All variables were considered fixed (planting date, hybrid, row spacing, and population). Regression analysis was used where appropriate. Effects were considered significant in all statistical calculations if P-values < 0.05.

Results and Discussion

Weather patterns for the 1998 and 1999 growing seasons were similar. The growing degree-day (GDD) accumulations for 1998 were 491 GDD in the South East and 197 GDD in the South West above the 30-year means (Table 4.1). In 1999, the South East portion of Michigan had 412 GDD and the South West had 79 GDD accumulations above the 30-year means. Precipitation was 4.1 and 6.1 inches below the 30-year norm for the South East portion Michigan in 1998 and 1999, respectively (Table 4.2). The South West portion of Michigan was 2.7 inches above the 30-year norm in 1998. In 1999, precipitation was 4.1 inches less than the 30-year norm. Timely rainfall during pollination and kernel fill helped to increase yields that would have otherwise been reduced. This drier than normal weather also attributed to a reduction in ECB pressure.

Table 4.1: Monthly growing degree day (GDD)[1] accumulation for the 1998-1999 growing seasons by regions. Thirty-year means have been included for comparison (1951-1980).

		Month						
Region	Year	May	June	July	Aug.	Sept.	Total	DEV
South East	1998	509	622	719	697	545	3092	491
	1999	437	645	811	617	503	3013	412
	30 yr.	353	542	658	616	432	2601	
South West	1998	473	557	681	681	512	2904	197
	1999	419	616	762	554	436	2786	79
	30 yr.	373	562	681	641	450	2707	

[1] GDD calculated at base 50°F, with 50°F and 86°F cutoffs.
Data courtesy of MSU Agricultural Weather Office.

Table 4.2: Monthly accumulated precipitation (inches) for the 1998- 1999 growing season. Thirty-year means have been included for comparison (1951-1980).

		Month						
Region	Year	May	June	July	Aug.	Sept.	Total	DEV
South East	1998	0.8	1.8	3.4	5.1	0.6	11.8	-4.1
	1999	3.5	2.0	2.0	1.3	1.0	9.8	-6.1
	30yr.	3.7	3.0	3.3	3.2	2.6	15.9	
South West	1998	1.8	4.4	2.9	8.4	2.0	19.4	2.7
	1999	1.7	2.8	3.5	2.8	1.9	12.6	-4.1
	30yr.	3.2	3.9	3.5	3.3	2.9	16.7	

Data courtesy of MSU Agricultural Weather Office.

The summary of the combined ANOVA table for 1998 and 1999 shows the significance of the main effects of location, hybrid, row spacing, population, and their interactions (Table 4.3). There were no traits that were statistically different between years. The only significant difference between hybrids was grain test weight. The lack of observed differences between hybrids could be due to the fact that all hybrids are near-isogenic. Row width was found to influence grain yield and stalk lodging. Plant population also influenced grain yield. There was only one trait that was significant for the two-way interaction of hybrid x row spacing, and that was test weight. The two-way interaction of row spacing x population showed a significant effect for percent grain moisture only. The two-way interaction of row spacing x population and the three-way interaction of hybrid x row spacing x population did not affect any of the traits observed.

Table 4.3: Narrow B*t* summary of combined analysis of variance for grain yield (GY), percent grain moisture (%H2O), test weight (TSTW), and stalk lodging (SL) for 1998 and 1999.

Source of variation	GY	%H2O	TSTW	SL
	P-values from ANOVA[1]			
Year	0.1709	0.9454	0.1672	0.2065
Hybrid	0.3250	0.3182	0.0243	0.2358
Row Spacing	0.0011	0.0995	0.6336	0.0048
Hyb*Row	0.5730	0.7814	0.0024	0.2621
Population	0.0001	0.1835	0.0677	0.2500
Hyb*Pop	0.4362	0.0255	0.4877	0.7667
Row*Pop	0.6777	0.7535	0.3105	0.5375
Hyb*Row*Pop	0.7018	0.1416	0.0632	0.5624

[1]Probability P = 0.05

Grain Yield

There were only two main effects that had an impact on grain yield. They were row spacing and plant population. The selection of hybrids that were near-isogenic eliminated any interaction of hybrids with grain yield. Grain yield increased as row spacing narrowed. The 15-inch row spacing had the largest, consistent increase in yield over the two years of the study. In 1998, 15-inch rows had a 6.6 bushels per acre yield advantage over the 30-inch rows (Table 4.4). There was also a 10.9 yield advantage of the 15-inch rows over the 30-inch rows in 1999. These large yield advantages resulted in an average of 8.7 bushels per acre increase for the 15-inch rows over the course of the two years. The 22-inch row spacing also had a yield advantage over the 30-inch rows but this was much smaller. The 22-inch row only had a 1.8 bushels per acre advantage, on average, over two years.

Yield performances of the three hybrids were closely related to plant population. As plant population increased from 25,850 to 31,004 plants per acre, there was a 6.5 bushels per acre increase in grain yield (Figure 4.1). When plant population increased from 31,004 to 35,728 plants per acre, there was only a 0.5 bushel per acre increase.

Table 4.4: Grain yields (Bu/Acre) by row spacing with advantage over 30-inch rows for comparison.

Row Spacing	1998[1]	1999	Average
30-inch	181.5b	155.5b	168.5b
22-inch	182.4ab	158.2ab	170.3b
15-inch	188.1a	166.3a	177.2a
	Advantage of Narrow Rows over 30-inch		
22-inch	---[2]	---	---
15-inch	6.6	10.95	8.7

[1] Grain yields within year and zone followed by the same letter are not significantly different.
[2] Comparison is not significantly different.

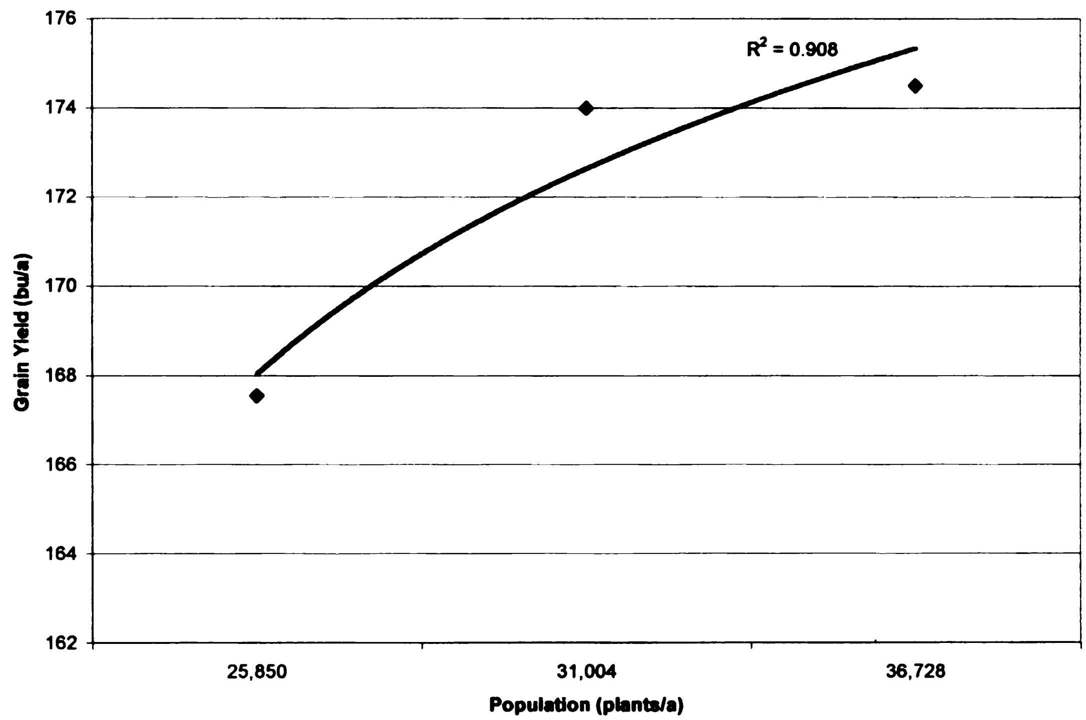

Figure 4.1: Grain yields by population. Regression equation for predicting grain yields from plant population is $y = 6.656Ln(pop) + 168.03$.

Grain Moisture

Grain moisture at harvest was affected by a hybrid and plant population interaction. There was a reduction in grain moisture for each hybrid as plant population increased. The hybrid DK 593BtX had the highest grain moisture content of all and decreased 0.1% in moisture as plant population increased (Figure 4.2). The largest drop in grain moisture was for DK 593BtY. It dropped 0.5% over the same span of population increase. The hybrid without any genetic modifications, DK 593, had a 0.1% drop in grain moisture as plant population increased from 25,850 to 36,728 plants per acre.

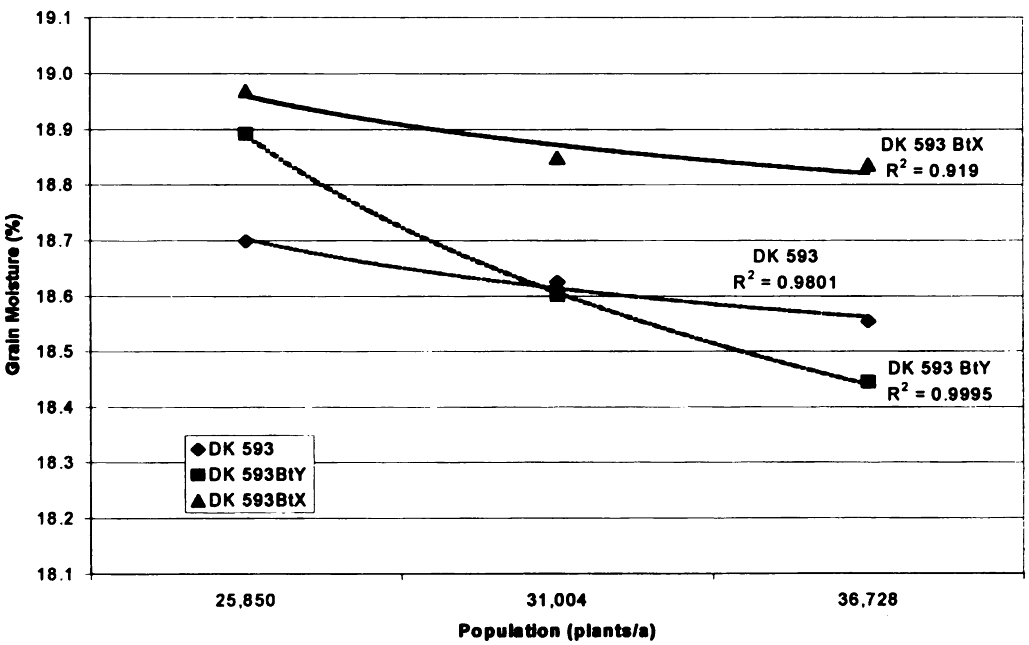

Figure 4.2: Grain moisture by population and hybrid. Regression equations for predicting grain moisture from population for each hybrid are:
DK 593 - $y = -0.1281\mathrm{Ln}(x) + 18.702$
DK 593 BtY - $y = -0.4091\mathrm{Ln}(x) + 18.889$
DK 593BtX - $y = -0.1271\mathrm{Ln}(x) + 18.96$

Test Weight

There were differences in test weight between hybrids even though the hybrids were near-isogenic. As one would expect, there were differences in test weight between years. Test weights were lower for the 1998-growing season (Figure 4.3). DK 583BtY had the lowest test weight in 1998 at 56.3 lbs., while DK 583BtX had the lowest test weight of 59.1 lbs. in 1999. DK 583 consistently had the highest test weight for both years. It weighed in at 57.1 and 60 lbs. for 1998 and 1999, respectively.

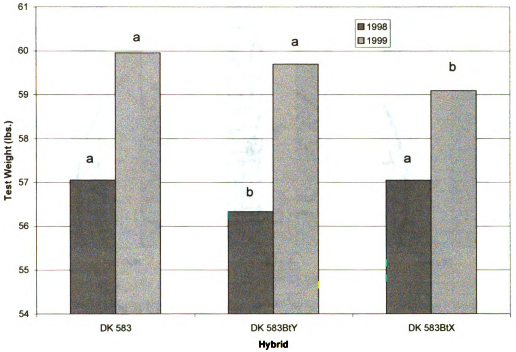

Figure 4.3: Test weight by hybrid and year. Columns within years followed by the same letter are not significantly different.

The interaction of hybrid and row spacing had an inconsistent affect on test weight. The transgenic hybrids were inconsistent in test weight as row spacing narrowed. The hybrid DK 593 consistantly had a reduction in test weight as row spacing narrowed. As row spacing narrowed to 22-inches from 30-inchs, DK 593 lost 0.2 lbs. in test weight (Figure 4.4). When row spacing was further narrowed to 15-inches, test weight continued to drop for DK 593 to 0.3 lbs. The total reduction in test weigh for DK 593 was 0.3 lbs. as the row spacing narrowed. There was a drop of 0.7 lbs. in test weight as row spacing for DK 593BtX narrowed from 30- to 22-inches. However, DK 593BtY had an increase of 0.3 lbs. as row spacing narrowed from 22- to 15-inches, resulting in a net gain in test weight.

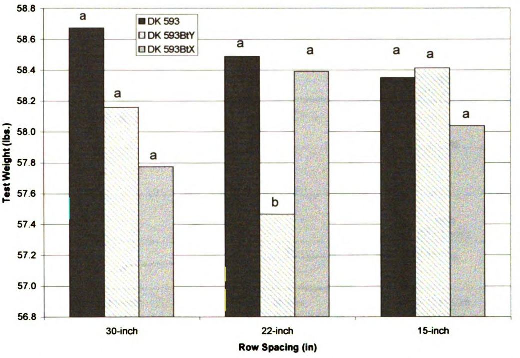

Figure 4.4: Test weight by row spacing and hybrid. Columns followed by the same letter are not significantly different.

Stalk Lodging

Row width was the only main effect that influenced stalk lodging. In 1998, the stalk lodging did not have as much variation as in 1999. In 1999, there was an unexplained exaggerated increase in stalk lodging in the 22-inch rows. Stalk lodging decreased as rows narrowed to the 15-inch row width (Figure 4.5). In 1998, stalk lodging did not drop below or increase above the level of the 30-inch rows. However, stalk lodging for 1999 dropped below the levels of the 30-inch rows when row width was narrowed to 15-inches.

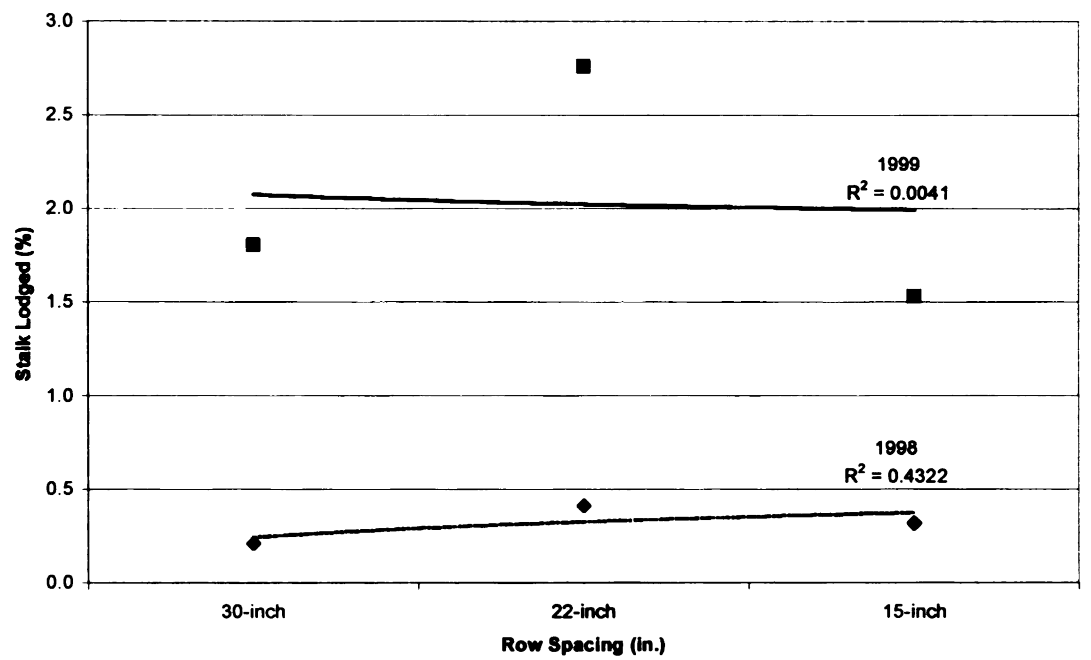

Figure 4.5: Stalk lodging by row spacing and year. Regression equations for predicting stalk lodging from row spacing within years are:
1998 - $y = 0.1193\text{Ln}(x) + 0.2417$
1999 - $y = -0.0742\text{Ln}(x) + 2.0742$

Conclusion

The selections of near-isogenic hybrids, as expected, eliminated any affect hybrids had on grain yield, grain moisture, and stalk lodging. Grain test weight was affected by the different hybrids. The test weights varied from hybrid to hybrid and from year to year.

Grain yield was affected by row width. The narrow rows out-yielded the wider 30-inch rows. The yield differences, on average, were as much as 8.2 and 1.8 bushels per acre for 15-inch and 22-inch row spacings, respectively. The 22-inch row spacing had the highest stalk lodging of any row spacing, while the 30- and 15-inch row spacings had less stalk lodging. There were different responses from year to year between row widths. The interaction of row spacing and hybrid also had a significant impact on test weight. The differences in test weight had more to do with hybrid reaction to row width than to row width alone.

Once again it was clear that plant population was of more importance to grain yield than were other factors. Grain yield increased as plant population increased. There was a 6.5 bushels per acre yield increase when plant population increased from low to high. Population did not effect grain moisture, test weight, or stalk lodging. The interaction between populations and hybrids had a significant affect on grain moistures. The effect of this interaction on grain moistures caused a reduction in moisture in each hybrid as population was increased from 25,859 to 36,728 plants per acre.

References

Beck, S. D. 1987. Development and seasonal biology of *Ostrinia nubilalis*. Agric. Zool. Rev. 2:59-96.

Feitelson, J. S., J. Payne, and L. Kim. *Bacillus thuringiensis*: Insects and Beyond.

Greaves, J. A., G. K. Rufener, M. T. Chang, and P. H. Koehler. 1993. Development of resistance to Pursuit herbicide in corn –the IT gene. Report of the 48th Annual Corn and Sorghum Research Conference. 48:104-118.

Hallauer, A. R., W. A. Russel, and K. R. Lamkey. 1991. Corn breeding. In G.F. Spargus and J. W. Dudleys, eds. Corn and Corn Improvement Volume 18. Agronomy, Madison, WI: American Society of Agronomy. pp 463-564.

Hayenga, M., L. C. Tompson, C. Chase, and S. Kaaria. 1992. Economic and enviromental implications of herbicide-tolerant corn and processing tomatoes. J. Soil Water Conserv. 47:411-417.

Hudon, M., E. J. LeRoux, and D. G. Harcourt. 1987. Seventy years of European corn borer (*Ostrinia nubilalis*) research in North America. Agri. Zool. Rev. 2:1-44.

Kells, J. J., K. Dysinger. 1996. Yield potential of selected IMI corn hybrids, *In* K. Dysinger, D. D. Harpsted, R. H. Leep, J. Lempke, M. Allen, and D. Mains, eds. Corn Hybrids Compared in the 1995 Season. Michigan State University Extension Bulletins E-431. p5.

Newhouse, K., B. Singh, D. Shaner, and M. Stidham. 1991a. Mutations in corn (Zea mays L.) conferring resistance to imidazoline herbicides. Theror. Appl. Genet. 83:65-70.

Newhouse, K., T. Wing, and P. Anderson, 1991b. Imidazolinone-tolerant crops. *In* D. L. Shaner, and S. L. O'Connor, eds. The Imidazolinone Herbicides. Boca Raton, Fl: CRC. pp. 139-150.

Rice, M. E. 1997. Bt corn: Its strengths and limitations. In Integrated Crop Management. Iowa State University Extension Bulletins. IC-478(2).

SAS Institute. 1985. SAS user's guide: Statistics. 5th ed. SAS Inst., Cary, NC.