PREDICTING OPTIMUM CORN POPULATIONS FOR CORN GROWN UNDER IRRIGATION IN KANSAS

by

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TABLE OF CONTENTS

INTRODUCTION

Corn (Zea mays L.) is the third most important crop in Kansas. In 1968, more than 85 million bushels were produced on slightly over one million acres in the state, with a record average yield of 75 bushels per acre.

Corn is the second most popular irrigated crop in the state, following grain sorghum. Corn responds well to good production practices, and yields of 200 bushels per acre and more have been reported in recent years.

Continued efforts by farmers, researchers and farm-service agencies have been successful in increasing average yields in spite of occasional unfavorable seasons. These efforts have resulted in an ever increasing level of technology applied toward producing the crop, and an increasing rate of change as well.

The number of input options from which a corn grower can select has increased several fold the past few years. It is not unusual for a farmer to have over 100 corn hybrids, ten or more herbicides and insecticides, and several tillage and harvesting options to choose from to apply to one corn crop. Obviously the selection of combinations of inputs is becoming more challenging.

As corn yields go up, small stresses that would not be noticed at lower yield levels become increasingly important. Therefore, increased knowledge of stress factors becomes imperative for the successful corn grower.

Personal experience in advising farmers on corn production practices including hybrid selections made clear some of the problems that were encountered in adapting and/or reproducing research results and recommendations to local conditions. Further experience in attempting to interpret research data emphasized the problems encountered in arriving at these recommendations in the first place. Appreciation of these two interrelated problems has led to the study of what is hopefully a practical method of resolving one of these problems.

This problem is the selection of the optimum plant population for a given corn hybrid under localized conditions. Optimum population appears to vary with level of production, maturity of the hybrid and possible other (unknown) factors, however, the solution of this problem appears to hold great promise.

A several bushel increase (or decrease) in yield simply by spending (or saving) a few cents per acre on seed is indeed a tempting goal for a farmer. Researchers might also be able to compare hybrids or fertilizer treatments at optimum densities rather than an arbitrarily chosen density which might favor some treatments over others, if optimum populations for a given hybrid could be determined.

The current cost-price squeeze on farm profits is causing some farmers to become more interested in early maturing hybrids that will permit double cropping the land. This interest is heightened by increasing evidence that early hybrids' relatively low yield category may be improved with increasing populations under good management conditions.

The problem of selecting optimum populations for the large number of hybrids commercially available, complicated by the relatively short life of many hybrids emphasizes the need for a new technique to determine these local optimum populations.

Traditional hybrid population studies have compared one or more hybrids, planted at a range of populations, often at different "productivity" levels. Most of these studies have been conducted in the corn belt and farther east and south. If more then one hybrid was used, an "adapted" hybrid plus a short and full season hybrid were most commonly used.

These studies have provided much useful information, however, they tend to be limited in number of hybrids evaluated, require more than one year's data to be most meaningful and are relatively high in manpower and space requirements. The applicability of such research data beyond a similar climatic and edaphic area would also be open to question.

Recent studies (3, 8, 9) in the western corn belt have indicated that hybrid by population interactions do exist, and that these interactions may be important factors in determining yields. Other research workers (1, 3) have reported that a mathmatical relationship might be useful in characterizing these hybrid by population interactions.

Therefore, this study was initiated with two objectives in mind: (1) to determine whether or not a linear relationship exits between the logarithm of grain yield per plant and number of plants per unit area for corn grown under irrigation in Kansas and (2) to determine if such a logarithmic relationship could adequately predict optimum populations under Kansas conditions.

LITERATURE REVIEW

The relationship of corn plant populations to yield has been studied for many years. It is common knowledge that corn is less capable of compensating for a poor stand than other cultivated grasses. Optimum populations for corn grown under different conditions range from 3 thousand (5) to 52 thousand (8) plants per acre.

Dungan, Lang and Pendleton (5) summarized corn plant populations, and soil productivity research rather completely up to 1958. Their conclusions generally recognized maturity as affecting optimum plant populations, but with soil productivity as the major factor determining yields. Experiments prior to the 1930's were largely with open pollinated varieties, and with hybrids thereafter. There was agreement by several investigators that hybrids generally had higher optimum populations than did varieties by approximately 2 thousand plants per acre under favorable growing conditions.

Dungan et. al (5) reported on the population and soil productivity research by corn producing regions of the United States - namely the East, South, Midwest and West with comments on European findings. Their summary of over 110 references cited only two studies for the West, which by their definition would include Kansas. Both of these studies were done prior to 1937 under dryland conditions, and contributed little information applicable to present day conditions and hybrids.

Troyer (8) in 1967 reviewed the literature on corn population-maturity research. He reported several studies that generally agree that earlier maturing hybrids could compensate somewhat for their smaller size and per plant yield disavantage by being planted in thicker stands. These studies also showed that generally the medium to full season hybrids outyielded the earlier hybrids, especially under favorable conditions. Stickler and Walter (7) reported similar results from Kansas dryland experiments, and concluded that stand density becomes more critical with increased productivity.

Colville et. al (3) studied six hybrids at four populations (12 to 24 thousand) over a four year period in a total of ten irrigated experiments in Nebraska. The latest maturing hybrid had an optimum population of 16 to 20 thousand, and the two earliest hybrids yielded most at 24 thousand plants per acre.

Troyer (8) also reported on a four year study at Mankato, Minnesota comparing hybrids by maturity groups at 16 and 22 thousand plants per acre. All maturity groups increased yields at the higher rate of planting. The overall relationship between maturity and yield showed a strong positive association between later maturity and higher yield; however, the response to increased population of the earlier hybrids was more than double the average of the later groups of hybrids.

A 1962 Minnesota study comparing four commercial hybrids of 80 to 105 day maturities with ten extremely early hybrids of 60 to 70 day maturities was reported by Troyer (8). The commercial hybrids were planted in 38 inch rows at 16.3 thousand plants per acre and the extremely early hybrids planted at 17, 35, 52 and 70 thousand plants per acre in 19 inch rows. Duplicate studies were planted May 2, June 3 and July 1. Extremely early hybrids responded dramatically to the 35 and 52 thousand populations for the May 2 and June 3 planting dates, yielding 40 percent more than the 17 thousand rate. The July 1 yields were drastically reduced, but the 35 and 52 thousand rates still yielded 25 percent more than the 17 thousand rate. In each case the hybrids planted at the 70 thousand rate yielded more than the 17 thousand rate, but below the 35 and 52 thousand rate. The top extremely early hybrids at their optimum rates yielded about the same as the 105 day hybrids at 16.3 thousand plants per acre.

Walter (10) reports that recent data from Kansas tests suggest that certain hybrids have a higher relative yield potential when planted at rates higher than those previously used in the performance tests. Kansas corn performance tests the past four years (1965-68) have been planted at two populations, with significant yield differences due to populations detected in most tests harvested.

Colville (2, 3), Stickler and Walter (7) and Vanderlip (9) reported significant hybrid by population interactions at several locations in Kansas and Nebraska, especially at higher yield levels. Some of these studies were conducted during every year since 1962, indicating the degree of interest in this type of research. The Kansas experiments by Vanderlip (9) have been conducted at 20 site years since 1966 under both irrigated and dryland conditions.

In 1958 Duncan (4) reported that for corn grown under midwest conditons there exists a linear relationship between the logarithm of grain yield per plant and the number of plants per unit area. In 1965, Carmer and Jackobs (1) proposed an exponential statistical model for predicting optimum plant density and maximum yields for corn hybrids using this linear relationship. They also presented evidence of the usefulness of the model for corn grown under Illinois climatic conditions.

MATERIALS AND METHODS

General

All performance data used in this investigation were drawn from a continuing state-wide hybrid population study carried on by Dr. R. L. Vanderlip in cooperation with agronomists at the various experiment fields and stations in Kansas. The author was one of those cooperating in the study each year at the Belleville Experiment Field.

Results from three of the irrigated locations were selected for this analysis. These locations provided the longest period of years data and represent major irrigation areas of the state. General procedures for this particular phase of study were formulated at the beginning of the hybrid population experiment.

Complete performance data for all locations included in the state-wide study for 1966 and 1967 may be found in Bulletin 519, "How Plant Populations Affect Yields of Corn Hybrids" from the Kansas Agricultural Experiment Station.

Hybrids

Eight commercially available, high yield potential hybrids were selected on the basis of performance in the Kansas Corn

Performance Tests. They were selected to give a range in maturity, response to population change, prolificacy, stalk characteristics and disease resistance. Data were used from irrigated studies at Colby, Tribune and Scandia, Kansas. Tests were conducted at all three locations in 1967 and 1968 and at Tribune and Scandia in 1966.

Each hybrid was grown at populations of 12, 16, 20, 24 and 28 thousand plants per acre in 30 inch rows. The plots were two rows 20 feet long, replicated four times. They were hand planted at twice the desired stand and then hand thinned soon after emergence.

The hybrids chosen and the descriptions provided by the respective companies follow (9):

U.S. 523W, orignially known aa K2299, is adapted to several states in this region. It has a smaller cob than most white hybrids and dries more rapidly in the fall. The shelling percentage of U.S. 523W is especially satisfactory. It has medium drought resistance and has done well throughout the Kansas corn belt. It is a full season double cross hybrid.

Nebraska 808 has a maturity rating of 122-126 days. In performance trials in areas of adaptation, this double cross, yellow hybrid has exhibited excellent yield records. Plants are intermediate in height, uniform and very dark green. Short thick shanks hold the ear erect until mature.

Pfisters Associated Growers SX29 is a single cross, yellow hybrid of medium maturity, medium to tall with medium-high ear placement. It has the ability to use high levels of fertility and available moisture for maximum yield results. Does well from 16 to 24 thousand plants per acre.

Pioneer 321 is a double cross, yellow hybrid with lots of foliage, good blight resistance, good roots and short shanks. Not quite so stiff stalked as some. It performs well under good dryland conditions and is a good producer under irrigation. For most of Kansas, it would be considered medium late in maturity.

Northrup King KT657, a double cross, yellow hybrid, is medium maturity for most of Kansas. Its population range is from 18 to 24 thousand plants per acre. It is a dark green leafy plant, medium height and ear placement, heat and drought tolerant with large diameter, medium length ears containing 18 to 20 rows of kernals.

DeKalb XL362 is a yellow medium maturity 3-way hybrid, 2 to 5 days later than 805A generally. It is a high population hybrid, usually performing best at 19 to 20 thousand plants per acre at harvest. It has a strong sturdy stalk, retains ears well, and picks or combines readily. It is one of DeKalb's more drought tolerant corns. Disease and insect resistance good to excellent.

DeKalb 805A is a yellow single cross hybrid of medium to medium early maturity that performs best at modest populations, not over 16 thousand plants per acre at harvest under favorable growing conditions. It has a distinctive long, straight rowed uniform ear. It is good to excellent in leaf blight resistance, fair to good in tolerance of European corn borer.

Locations

All tests were grown on Kansas State University Agricultural Experiment Stations at Colby and Tribune and on the Irrigation

Experiment Field near Scandia. Station and field personnel assisted with all phases of the tests. Planting dates, fertilization, precipitation and irrigation data and soil types are presented in Table 1.

Irrigation water for the Tribune and Colby stations was from deep wells, while surface water from the Kansas-Bostwick irrigation district was used at Scandia.

Statistical Procedures

A logarithmic transformation (to base e) of grain yield per plant (log W) was made for each plot harvested. The log W values were programmed into the data output from the Kansas State University IBM 360/50 computer. They were calculated by multiplying ear weight per plant by shelling percentage to get grain production per plant. The grain yield was reported for actual population at harvest and at 15.5 percent moisture.

Regression analyses on these log W values over the population range studied were performed on the K. S. U. IBM 360/50 computer.

Regression analyses were performed for (a) individual hybrids for each location and year, (b) hybrids combined over locations and years, (c) hybrids by locations over years and (d) combined over hybrids for each location-year.

Covariance analysis was then used to compare the regressions for (a) and (b); (a) and (c); and (a) and (d) (Fryer (6)). F tests were performed to test significant differences in the intercepts and slopes.

Table 1. Soil type, planting date, fertilizer applied, rainfall and irrigation water applied for corn hybrid population studies at Colby, Tribune and Scandia, Kansas 1966-68.

Year and location	Soil Type	Planting Date	Fertilizer Application lbs./A N	P	K	April-Sept. Rainfall (inches)	Normal April-Sept. Rainfall (inches)	Irrigation Water added (inches)
1966								
Tribune	Ulysses sl	May 10	222+0[1]	63+0	0+0	12.49	12.66	23.8
Scandia	Crete sl	April 29	2000+18	0+21	0+0	16.41	18.92[2]	19.2
1967								
Colby	Kieth sl	May 12	267+20	38+9	0+17	9.96	13.93	10.1[3]
Tribune	Ulysses sl	May 10	289+0	35+0	0+0	14.3	12.66	23.7
Scandia	Crete sl	May 14	290+16	0+21	0+0	27.58	18.92[2]	19.2
1968								
Colby	Kieth sl	May 13	200+0	0+0	0+0[4]	15.87	13.93	10.1[3]
Tribune	Ulysses sl	May 13	292+0	79+0	0+0[5]	9.32	12.66	23.8
Scandia	Crete sl	May 9-10	264+36	0+92	0+0	32.83	18.92[2]	19.2

1. Second value indicates fertilizer applied at planting
2. Concordia, Kansas data used
3. Plus preirrigation
4. Plus 12 lbs. zinc
5. Plus 9 lbs. zinc

RESULTS AND DISCUSSION

The first objective of this study was to determine if a linear relationship exists between the logarithm of grain yield per plant and number of plants per unit area for corn grown under irrigation in Kansas. If such a relationship exists and can be characterized in some consistent manner, it may be useful in achieving the second objective, which was to predict optimum populations for a given hybrid using data from a single hybrid population study.

Plant Yield and Population Relationship

Simple linear regression analyses were performed on the log W values (appendix tables 1-8) for each hybrid for each location-year. The correlation coefficients are presented in table 2.

All but four of the individual hybrid-location correlation coefficients have values above -0.90, indicating good fit of a linear regression line. The lower correlation coefficients were for DeKalb XL362 (Tribune 1967 and Scandia 1966 and 1968) and DeKalb 805A (Tribune 1967). Examination of the yield data (appendix tables 9-15) for the two hybrids revealed such unusual variability that they were not considered as representative performances for these hybrids.

Mean (over replications) log W values for each hybrid were plotted to compare fit with the calculated regression slopes. Individual graphs were prepared plotting each hybrid over location-year and location-years over hybrids. These graphs permitted simultaneous visual comparison of the calculated slopes of each hybrid

Table 2. Correlation coefficients for each hybrid at each location-year.

	Colby		Tribune			Scandia		
Hybrids	1967	1968	1966	1967	1968	1966	1967	1968
U.S. 523W	-0.946	-0.964	-0.982	-0.930	-0.970	-0.930	-0.952	-0.956
Neb. 808	-0.954	-0.947	-0.965	-0.955	-0.967	-0.955	-0.967	-0.978
P.A.G. SX29	-0.959	-0.966	-0.964	-0.947	-0.983	-0.946	-0.942	-0.946
Pio. 321	-0.966	-0.956	-0.973	-0.939	-0.964	-0.930	-0.960	-0.947
N.K. KT657	-0.966	-0.952	-0.988	-0.913	-0.976	-0.920	-0.953	-0.969
DK. XL362	-0.937	-0.979	-0.847	-0.930	-0.919	-0.616	-0.930	-0.872
DK. 805A	-0.941	-0.916	-0.938	-0.805	-0.937	-0.962	-0.930	-0.967

with the mean log W points for all location years and of hybrids for each location-year.

Mean log W values and calculated regression lines for Nebraska 808 grown at Scandia in 1966, 1967 and 1968 are presented in figure 1. This example illustrates a typical scatter of points about the calculated regression lines found for all hybrids. There was no consistent pattern of points about the fitted lines that indicated any curvilinear response and no further statistical tests were made to determine curvilinear fit.

The conclusion was drawn that a linear relationship exists between the logarithm of grain yield per plant and number of plants per unit area, for the hybrids studied within the population range studied.

Prediction of Optimum Populations

The second objective of this study was to predict optimum populations for a given corn hybrid with data from a single hybrid population study. This would require a single log W versus population regression line that would adequately characterize a hybrid over a reasonable population range.

Examination of the individual regression analyses revealed a considerable range of intercept and slope values for hybrids at different locations and years. The log W data were combined for each hybrid over all location-years, and linear regression analyses performed to determine if a single regression line could be found.

The calculated intercept (a), slope of the fitted regression line (b), and correlation coefficients (r) for the individual

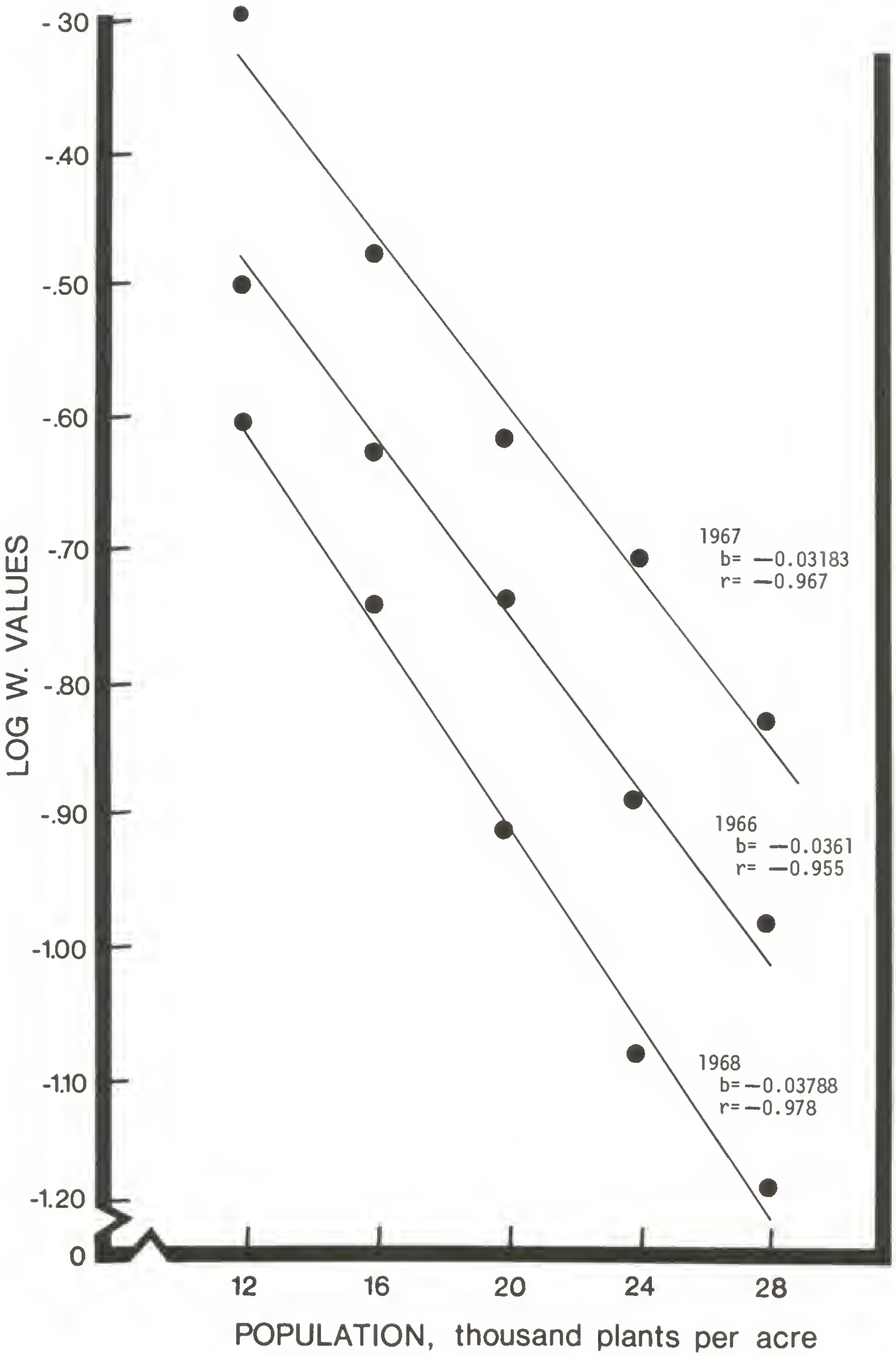

Fig. 1. Fitted regression lines and mean log W points for Nebraska 808. Scandia 1966-68.

and combined regression analyses for each hybrid are presented in tables 3 through 9. A "yield level" column is also included that report yields averaged over all five populations (12-28 thousand plants per acre).

U.S. 523W. The slopes of the fitted regression line for U.S. 523W range from -0.05886 (Colby 1967) to -0.03876 (Tribune 1968), and the calculated intercepts vary from 0.31230 (Colby 1968) to -0.03964 (Tribune 1968). A positive relationship between yield level and intercept was evident, but was affected by slope. For example, the yield level for Colby 1967 and Scandia 1968 was 132 bushels per acre, but the steeper slope (-0.05886 vs. -0.05212) for Colby 1967 resulted in a higher intercept (0.22211) for Colby than for Scandia (0.08439). The combined slope and the Scandia 1967 slope are identical (-0.04189), but were at different heights as indicated by the intercepts and yield levels.

The correlation coefficient for the combined over location-years regression was lower than any of the individual values due to height differences. This relationship was consistent for all hybrids tested.

Nebraska 808. Nebraska 808 generally yielded higher than U.S. 523W and was more consistent in performance. The range of slope values was less (-0.05072 Colby 1967 to -0.03183 Scandia 1967) and the individual slopes at each location were less as well. A general relationship may be noted from tables 3 and 4, that as yield levels went up, the slope of the regression line decreased. The yield levels for Scandia 1967 and 1968 were 194 and 139 bushels, respectively, and corresponding slopes were -0.03183 and -0.03788.

Table 3. Regression analysis data for U.S. 523W by location-year and combined over location-years.

Location and year		Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)	Yield level (Bu.)
Colby	67	0.22211	-0.05886	-0.946	132
	68	0.31230	-0.06485	-0.964	130
Tribune	66	0.28036	-0.05565	-0.982	149
	67	0.22072	-0.05019	-0.930	160
	68	-0.03964	-0.03876	-0.969	153
Scandia	66	0.22599	-0.04761	-0.930	168
	67	0.13948	-0.04189	-0.952	171
	68	0.08439	-0.05212	-0.956	132
Combined overall		0.11063	-0.04189	-0.856	149

Table 4. Regression analysis data for Nebraska 808 by location-year and combined over location-years.

Location and year		Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)	Yield level (Bu.)
Colby	67	0.28338	-0.05072	-0.953	165
	68	0.13508	-0.04798	-0.947	150
Tribune	66	0.12433	-0.04177	-0.965	169
	67	0.14745	-0.04506	-0.955	163
	68	0.01003	-0.03860	-0.967	158
Scandia	66	-0.03261	-0.03631	-0.956	158
	67	0.05974	-0.03183	-0.967	194
	68	-0.14712	-0.03788	-0.978	139
Combined overall		0.06576	-0.04082	-0.889	162

P.A.G. SX29. The combined yield level of 167 bushels per acre for P.A.G. SX29 was the highest for any of the hybrids tested, and the combined intercept reflects this level of production. The correlation coefficients were all uniformly high, and the combined value was the highest for any hybrid tested. The variances for slope and intercept were also relatively low, adding to the evidence that SX29 performed well and very consistently over locations and years.

Table 5. Regression analysis data for P.A.G. SX29 by location-year and combined over location-years.

Location and year		Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)	Yield level (Bu.)
Colby	67	0.32412	-0.04955	-0.959	176
	68	0.20336	-0.05325	-0.966	146
Tribune	66	0.18672	-0.04151	-0.964	180
	67	0.07448	-0.03892	-0.947	172
	68	0.07609	-0.04010	-0.983	165
Scandia	66	0.10044	-0.03969	-0.946	172
	67	0.04328	-0.03110	-0.942	194
	68	-0.15321	-0.03955	-0.946	134
Combined overall		0.19015	-0.05174	-0.893	167

Pioneer 321. Pioneer 321 had a slope second lowest in numerical value of all the hybrids, reflecting high yield level. The combined yield of 162 bushels in table 6 was also second highest (tied with Nebraska 808) of all. This hybrid performed

especially well at higher populations, (as indicated by the yield data in appendix table 12) with a 24 thousand population mean yield of 174 bushels per acre. Relatively low variances reflect the consistent performance of this hybrid over the population range at all locations and over years.

Table 6. Regression analysis data for Pioneer 321 by location-year and combined over location-years.

Location and year		Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)	Yield level (Bu.)
Colby	67	0.17919	-0.04410	-0.966	170
	68	0.10578	-0.04857	-0.956	144
Tribune	66	0.13942	-0.03960	-0.973	180
	67	0.04832	-0.03779	-0.939	170
	68	0.15522	-0.04563	-0.964	162
Scandia	66	0.00711	-0.03868	-0.930	160
	67	0.08603	-0.03910	-0.960	186
	68	-0.22599	-0.03649	-0.947	132
Combined overall		0.05531	-0.04038	-0.861	162

Northrup King KT657. Northrup King KT657, table 7, may be characterized as a "medium" hybrid by comparing the combined slope, intercept and correlation coefficient with the others. The average yield level was fairly high, as was the optimum population of 24 thousand plants per acre (appendix table 13). This hybrid occasionally exhibited wildly fluctuating yields at different populations.

Table 7. Regression analysis data for Northrup King KT657 by location-year and combined over location-years.

Location and year		Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)	Yield level (Bu.)
Colby	67	0.36988	-0.05285	-0.966	173
	68	0.14969	-0.05240	-0.952	139
Tribune	66	0.32247	-0.05027	-0.988	174
	67	0.13334	-0.03906	-0.913	181
	68	-0.00904	-0.03843	-0.976	158
Scandia	66	0.26081	-0.05637	-0.920	148
	67	0.02846	-0.03268	-0.953	185
	68	-0.15930	-0.03989	-0.969	132
Combined overall		0.12572	-0.04466	-0.852	161

<u>DeKalb XL362</u>. DeKalb XL362, table 8, had the flattest combined slope, the lowest intercept, the lowest correlation coefficient and the second lowest average yield of the hybrids tested. The relatively early maturity may account for the yield disadvantage, but the Scandia 1966 location-year performance accounted for a large part of the variability reflected in the combined data. Yields were extremely variable between replications, and averaged less than 100 bushels per acre up to 16 thousand population, then jumped to 130 bushels at 24 thousand, and dropped to 120 bushels at 28 thousand. This extremely inconsistent behavior was also exhibited by DeKalb 805A for this location year. No explanation for these erratic performances was apparent.

Table 8. Regression analysis data for DeKalb XL362 by location-year and combined over location-years.

Location and year		Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)	Yield level (Bu.)
Colby	67	0.03230	-0.04032	-0.937	158
	68	-0.08196	-0.04093	-0.911	140
Tribune	66	0.06510	-0.04295	-0.979	155
	67	-0.07125	-0.03490	-0.847	158
	68	-0.16720	-0.03633	-0.919	143
Scandia	66	-0.52560	-0.03048	-0.616	111
	67	-0.20715	-0.02721	-0.930	163
	68	-0.52001	-0.06281	-0.872	117
Combined overall		-0.18336	-0.03519	-0.730	143

<u>DeKalb 805A</u>. DeKalb 805 A, table 9, is a single cross hybrid that almost consistently exhibited the lowest optimum population and had the lowest average yield of all the hybrids tested. The steep (-0.05243) slope and low yield level (142 bu.) serve to illustrate another general characteristic that was consistent for the log W lines for all hybrid, that is, the lower the maximum yield, the lower the optimum population tended to be. This feature may be verified by examining the individual location-year data in tables 3 through 9.

The regression analysis data for individual hybrids combined over all location-years is presented in table 10.

Table 10. Regression analysis data for individual hybrids combined over all location-years.

Hybrid	Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)	Yield level (Bu.)
U.S. 523W	0.11063	-0.04189	-0.856	150
Neb. 808	0.06576	-0.04082	-0.889	162
P.A.G. SX29	0.19015	-0.05174	-0.893	167
Pio. 321	0.05531	-0.04038	-0.861	162
N.K. KT657	0.12572	-0.04466	-0.852	161
DK XL362	-0.18336	-0.03519	-0.730	143
DK 805A	0.15020	-0.05243	-0.823	142

Covariance analyses were then performed comparing the combined and individual slopes and intercepts. The results of these tests are reported in table 11.

Table 11. Analysis of covariance for hybrids combined over years and locations.

Hybrid	Error d.f.	F ratios for Intercept (a)	F ratios for Slope (b)
U.S. 523W	144	25.62**[1]	5.12**
Neb. 808	144	30.80**	7.20**
P.A.G. SX29	144	62.60**	3.00**
Pio. 321	144	33.66**	14.00**
N.K. KT657	144	52.50**	6.33**
DK XL362	144	40.73**	2.0
DK 805A	144	39.15**	4.54**

[1] One asterisk (*) indicates significance at the 5% level and two asterisk (**) indicates significance at the 1% level.

Significant differences were found between intercepts for all hybrids and significant slope differences for all hybrids except DeKalb XL362. A comparison of the slope values for DeKalb XL362 in table 8 with other hybrids' values shows that it does have a very limited range.

Evidence at this point indicated that neither individual nor combined hybrid location-year data was adequate for prediction of optimum plant populations.

Further examination of the plotted log W values revealed that for hybrids with high optimum populations, the mean log W point for 12 thousand population tended to be below the fitted line. Another set of linear regression analyses was made for individual and combined hybrid location-years, omitting data for the 12 thousand population. These analyses gave lower r values (correlation coefficients) and greater variances than did the set using 12 to 28 thousand population range. Therefore, no further tests were made using this range.

The next step in attempting to characterize a single prediction line was to examine all hybrids for each location-year. It had been noted that the slopes for all hybrids at a single location-year tended to be rather close together and follow the same general trend. It was postulated that possibly a location or location-year effect was affecting all hybrids similarly and that this might mask hybrid differences. Therefore, location-year regressions combined over hybrids were compared to individual regressions. The regression analysis data for location-years combined over hybrids is presented in table 12 and the covariance analyses results are reported in table 13.

Table 12. Regression analysis data for location-years combined over hybrids.

Location and year		Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)
Colby	1967	0.22920	-0.04964	-0.902
	1968	0.12051	-0.04996	-0.925
Tribune	1966	0.21009	-0.04680	-0.930
	1967	0.07119	-0.04096	-0.847
	1968	0.00771	-0.04062	-0.921
Scandia	1966	0.08369	-0.04825	-0.693
	1967	0.03980	-0.03476	-0.890
	1968	-0.15347	-0.04132	-0.909

Table 13. Analysis of covariance for location-years combined over hybrids.

Location and year		Error d.f.	F ratios for Intercept (a)	Slope (b)
Colby	1967	126	2.12	0.04
	1968	126	6.40**	2.50*
Tribune	1966	126	2.35*	7.20**
	1967	126	10.42**	1.49
	1968	126	18.16**	2.98**
Scandia	1966	126	68.52**	12.13**
	1967	126	20.75**	4.52**
	1968	126	13.86**	8.47**

Significant differences were found for all intercepts except Colby 1967 and for all slopes except Colby 1967 and Tribune 1967. Therefore, individual hybrids tested did have characteristic hybrid by population differences that were not masked by location effects.

The next effort to identify a single line for predictive purposes consisted of comparing data for each hybrid at each location combined over years. The regression analysis data for this combination are reported in tables 14 through 20.

Table 14. Regression analysis data for U.S. 523W for each location combined over years.

Location	Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)
Colby	0.26110	-0.06152	-0.953
Tribune	0.16855	-0.04906	-0.949
Scandia	0.15635	-0.04751	-0.867

Table 15. Regression analysis data for Nebraska 808 for each location combined over years.

Location	Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)
Colby	0.18985	-0.04821	-0.942
Tribune	0.08501	-0.04128	-0.956
Scandia	-0.05617	-0.03450	-0.790

Table 16. Regression analysis data for P.A.G. SX29 for each location combined over years.

Location	Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)
Colby	0.26082	-0.05125	-0.914
Tribune	0.11464	-0.04029	-0.954
Scandia	-0.00885	-0.03645	-0.755

Table 17. Regression analysis data for Pioneer 321 for each location combined over years.

Location	Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)
Colby	0.11145	-0.04465	-0.912
Tribune	0.12689	-0.04174	-0.942
Scandia	-0.06353	-0.03576	-0.772

Table 18. Regression analysis data for N.K. KT657 for each location combined over years.

Location	Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)
Colby	0.24947	-0.05230	-0.898
Tribune	0.16350	-0.04335	-0.934
Scandia	-0.00963	-0.04008	-0.787

Table 19. Regression analysis data for DK XL362 for each location combined over years.

Location	Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)
Colby	-0.04026	-0.03983	-0.890
Tribune	-0.03286	-0.03944	-0.904
Scandia	-0.45424	-0.02672	-0.567

Table 20. Regression analysis data for DK 805A for each location combined over years.

Location	Calculated Intercept (a)	Slope (b)	Correlation Coefficient (r)
Colby	0.11170	-0.04660	-0.925
Tribune	0.13937	-0.04933	-0.873
Scandia	0.13779	-0.05675	-0.798

Each of the individual hybrid location year slopes were compared to the respective combined slopes. Results of these covariance analyses are reported in table 21.

All of the F values for slope differences were insignificant at Colby, as were five at Tribune and two at Scandia. The general conclusion that progress had been made in identifying characteristic slopes, if not intercepts, was indicated. The number of significant differences at Tribune and Scandia also indicated that problems still exist in using this combination of data for prediction purposes.

Table 21. Analysis of covariance for individual hybrids combined over years for Colby, Tribune, and Scandia.

	Colby			Tribune			Scandia	
	Error	F ratios for		Error	F ratios for		F ratios for	
Hybrid	d.f.	intercept	slope	d.f.	intercept	slope	intercept	slope
U.S. 523W	36	14.00**	1.42	58	35.40**	20.0**	112.30**	4.74*
Neb. 808	36	0.0007	0.00	58	4.50	2.50	438.20**	5.04*
P.A.G. SX29	36	26.80**	0.28	58	21.66	0.33	236.00**	6.14*
Pio. 321	36	41.67**	1.00	58	26.75**	4.50*	24.47**	0.58
N.K. KT657	36	6.23**	0.13	58	21.75**	2.50	188.30**	22.1**
DK XL362	36	27.00**	0.00	58	27.33**	3.00	110.10**	0.02
DK 805A	36	3.70	2.77	58	17.80**	0.80	214.41**	43.92**

All tests made up to this point indicate that no single log W slope and/or intercept considered would permit accurate prediction of optimum populations for all hybrids at all locations. Therefore, no further tests or comparisons were made to find a single data set from which to predict optimum populations.

Utilization of Model for Interpretation

Some of the variabilities of the log W slopes that prevented finding one representative slope and intercept were found to have certain predictable characteristics. The recognition of these characteristics has suggested a different and rather promising use of the logarithmic model in interpreting corn performance data.

A very brief and general explanation of the usefulness of the proposed model follow with examples illustrating general procedures.

Corn performance tests grown at two populations often give much more information about optimum population than single population tests. Even so, it is not possible to select any two populations that are equally favorable for all hybrids in the test. More populations or varying the populations for different hybrids is usually not feasable.

One important feature lacking in the two population performance test is an estimate of whether or not one of the arbitrarily selected test populations is optimum, or whether the optimum is above or below either test density.

Use of the logarithmic transformation in projecting a per acre yield curve based on the yields at the two performance test populations provides an estimate of the optimum populations and theoretically should estimate the maximum yield for the test conditions.

The yields for Nebreaka 808 from the Republic county (Scandia) irrigated corn performance tests for 1967 and 1968 were used to calculate log W points plotted in figures 2 and 3. A line was extended through the points to intersect the 12 through 28 thousand population range on the axis. Log W values taken from this line were then used to calculate yields for each population used in the hybrid population study. These yields were then plotted and compared with the observed yields from the performance tests. As would be expected from such approximate procedures, the calculated yield curves failed to pass directly through the observed performance test yfeld points. Rounding errors in calculating, and inaccurate plotting, together with the fact that a fitted regression line would undoubtedly be different from the one using rounded, mean values may account for the discrepancy. It should also be recognized that potential error is increasingly great as points are extrapolated beyound the observed population range, especially for higher populations. The potential error from rounding and plotting naturally increases with higher populations.

The yields for Nebraska 808 from the hybrid population study, also grown at Scandia in 1967 and 1968 were then plotted in figures 2 and 3. Yields from the hybrid population study were higher than for the performance test, especially in 1967. The performance test was located in a less favorable location on the field.

Most difference in yields occurred at the 24 to 28 thousand populations. The difference illustrates the relationship that as yields went higher, so did optimum populations.

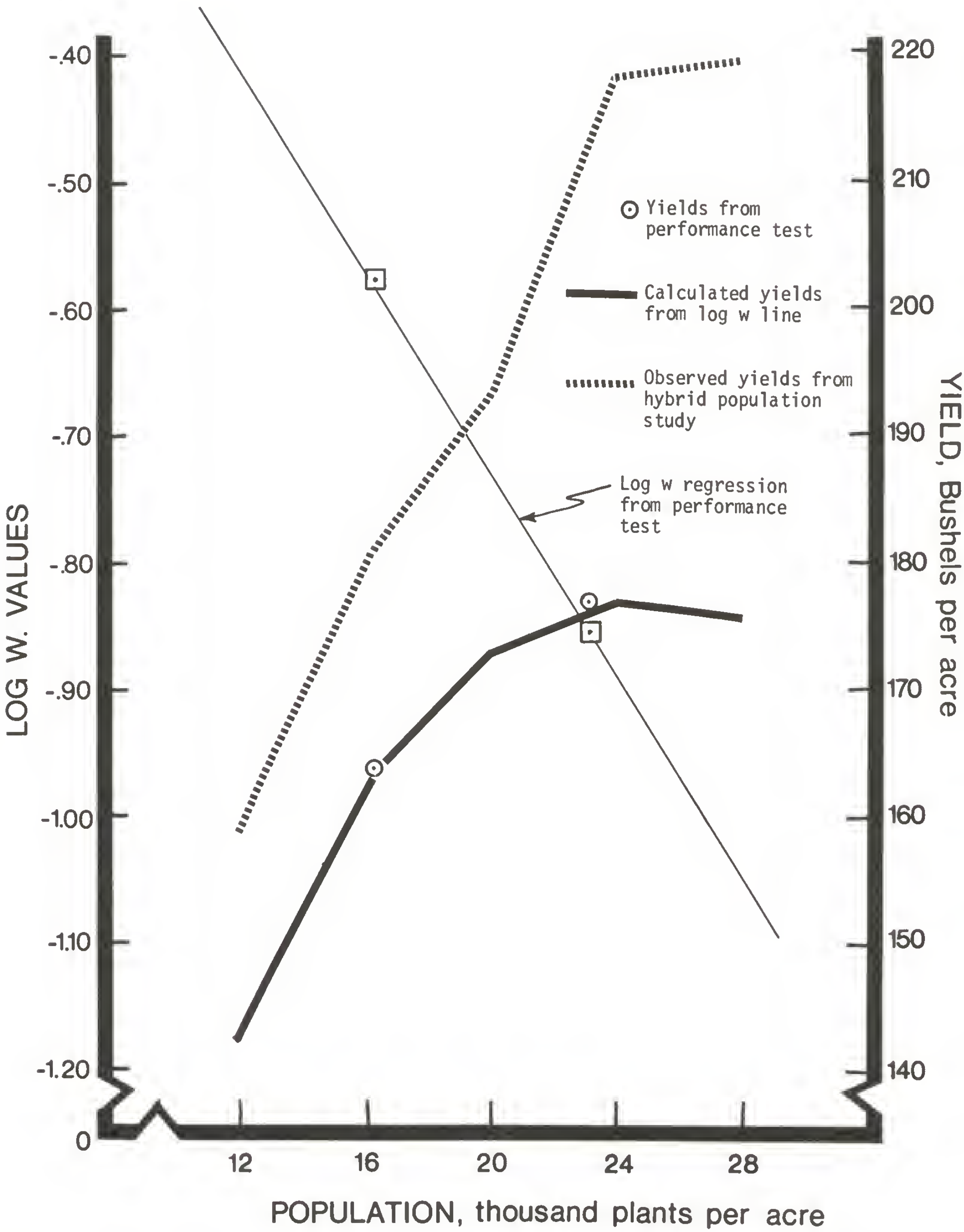

Fig. 2. Comparison of calculated and observed yield curves for Nebraska 808 at Scandia in 1967.

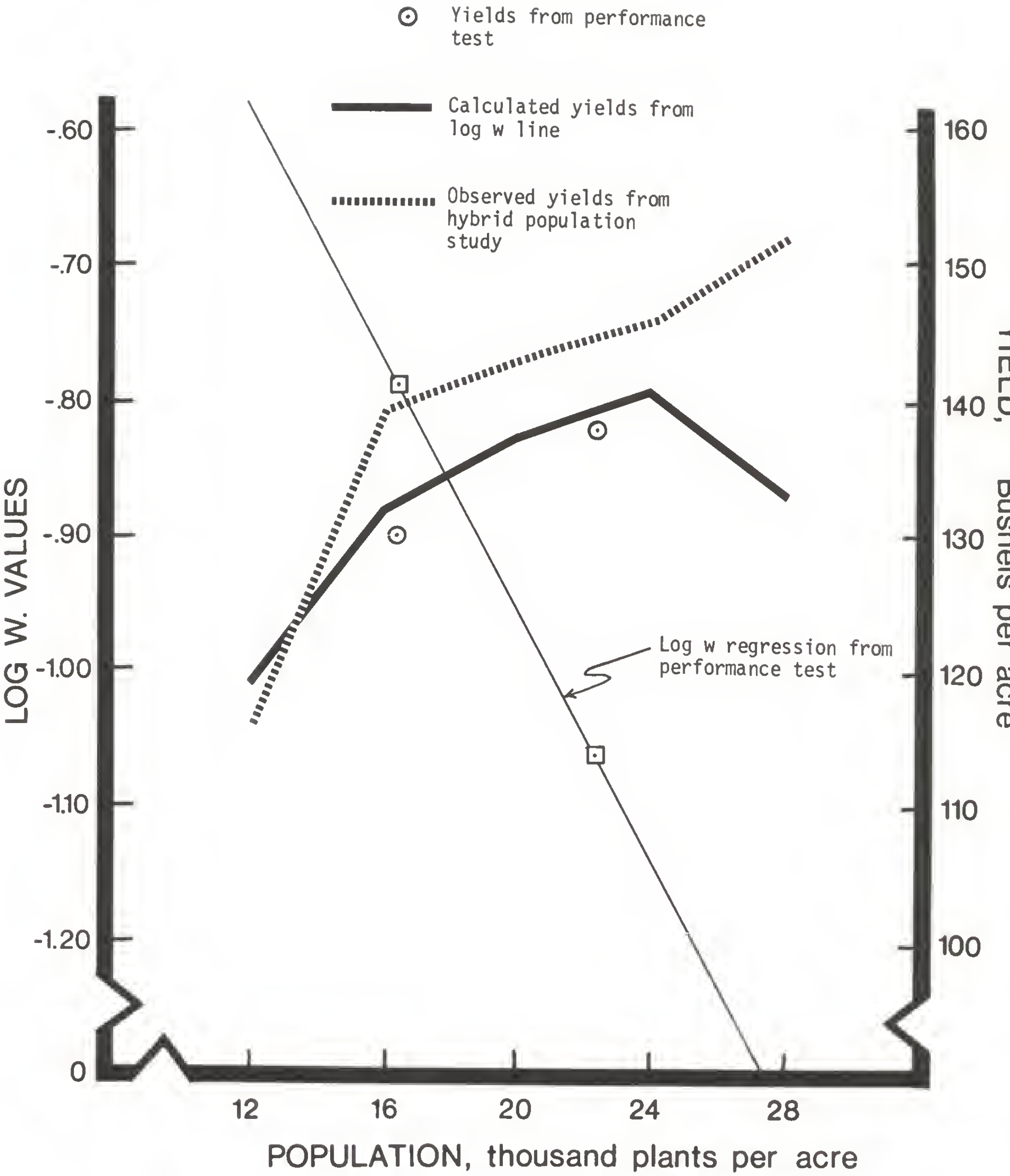

Fig. 3. Comparison of calculated and observed yield curves for Nebraska 808 at Scandia in 1968.

From 12 thousand up to the highest population in the performance test (approximately 23 thousand), the calculated yield curves closely approximated the shape of the hybrid population yield curves. Within the range of (and slightly beyond) the two population of the corn performance tests (approximately 17 and 23 thousand) the shape of the yield curve was the same as that from the hybrid population study for the same location-year.

A greater range in the two populations of the corn performance tests, especially a higher maximum, would undoubtedly give a better estimate of the yield curve than extrapolation beyond the observed range. Fitting a regression line using all replicate yields (or log W values) should also improve the accuracy.

Evidence that yield curves calculated from log W lines fit the observed yield curves is presented in figure 4. Yield curves for U.S. 523W were calculated for populations from 8 to 32 thousand plants per acre, using the individual location-year data from table 3 for Scandia 1967 and 1968. The calculated curves were then plotted with the observed mean (over replications) yields plotted as points around the curve. (Similar curves were plotted for each hybrid at each location-year with similar results).

The slope and the intercept would already be determined by the yield at the different populations of a corn performance test, and theoretically at least, an optimum population and maximum yield could be calculated for any hybrid at any location in Kansas.

No further development of the proposed use of the exponential model has been accomplished, although data is available to test it extensively.

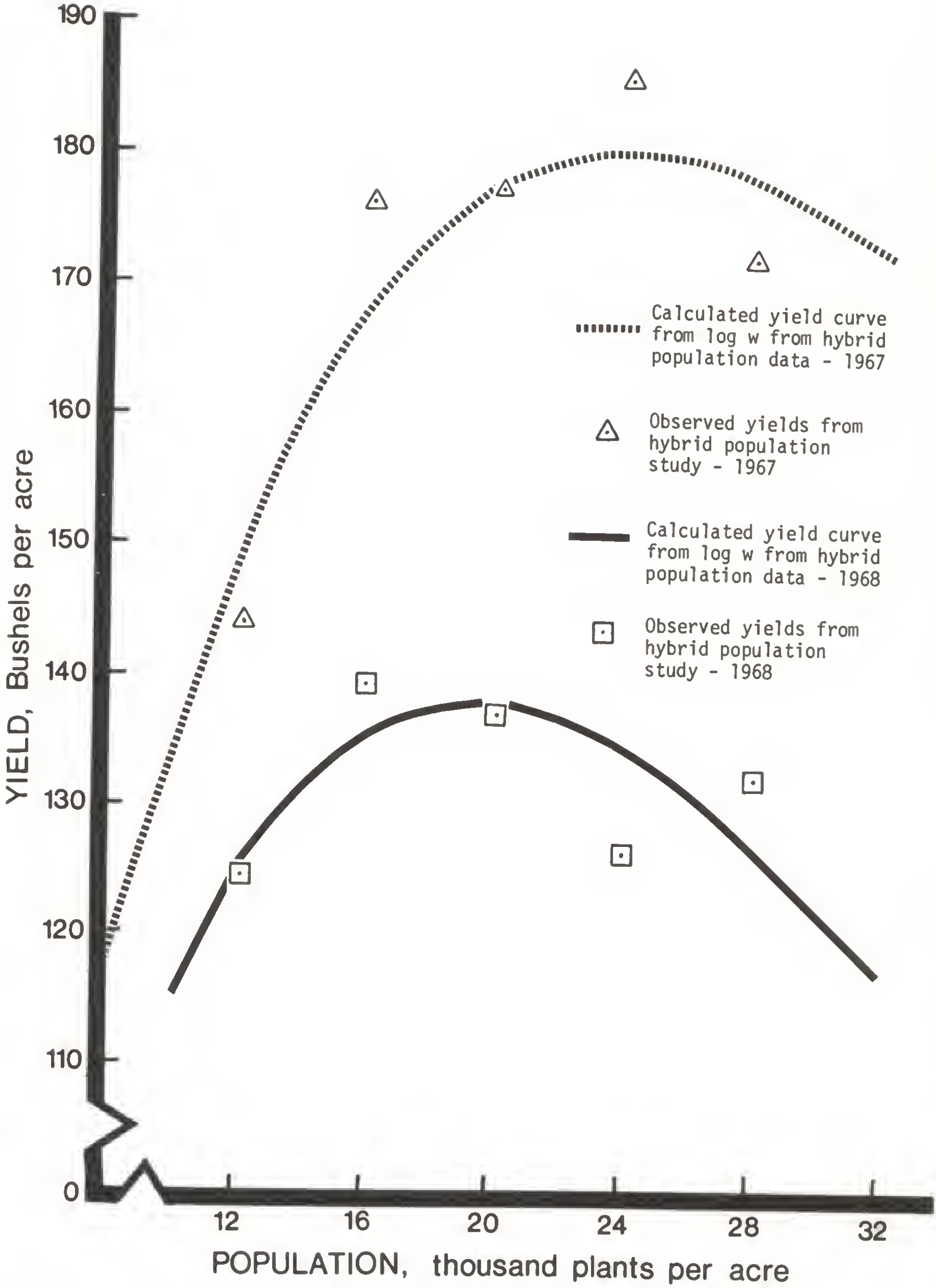

Fig. 4. Calculated yield curves and observed yields for U.S. 523W. Scandia 1967 and 1968.

SUMMARY AND CONCLUSIONS

A linear relationship between the logarithm of yield per plant and the number of plants per unit of land area was found to exist for corn grown under irrigation in Kansas.

No satisfactory individual or combination of individual slopes or intercepts were found to predict optimum populations for all hybrids at all location-years studied. Characteristic variations occurred in the log W regression corresponding to yield level and optimum population for different hybrids.

A plan was proposed to make use of the logarithmic transformations in interpreting corn performance data when grown at two plant populations, with examples presented to suggest general methods that might be used.

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APPENDIX

Table 1. Log W values for Colby, 1967.

Hybrid	Population					
	12,000	16,000	20,000	24,000	28,000	Average
U.S. 523W	-0.45	-0.68	-0.88	-1.28	-1.37	-0.93
Neb. 808	-0.26	-0.55	-0.76	-0.94	-1.13	-0.73
P.A.G. SX29	-0.27	-0.47	-0.65	-0.80	-1.08	-0.66
Pio. 321	-0.34	-0.54	-0.69	-0.91	-0.98	-0.69
N.K. KT657	-0.27	-0.52	-0.64	-0.88	-1.10	-0.68
DK XL362	-0.52	-0.54	-0.76	-0.88	-1.14	-0.77
DK 805A	-0.43	-0.58	-0.78	-1.07	-1.18	-0.81
Population mean	-0.37	-0.56	-0.74	-0.97	-1.14	

Table 2. Log W values for Colby, 1968

Hybrid	Population					
	12,000	16,000	20,000	24,000	28,000	Average
U.S. 523W	-0.49	-0.70	-0.89	-1.20	-1.43	-0.94
Neb. 808	-0.38	-0.57	-0.81	-0.95	-1.14	-0.77
P.A.G. SX29	-0.41	-0.64	-0.88	-1.09	-1.21	-0.85
Pio. 321	-0.42	-0.68	-0.78	-0.97	-1.15	-0.80
N.K. KT657	-0.47	-0.66	-0.88	-1.05	-1.30	-0.87
DK XL362	-0.60	-0.67	-0.86	-1.05	-1.18	-0.87
DK 805A	-0.47	-0.62	-0.72	-0.97	-1.07	-0.77
Population mean	-0.46	-0.65	-0.83	-1.04	-1.21	

Table 3. Log W values for Tribune, 1966.

Hybrid	Population 12,000	16,000	20,000	24,000	28,000	Average
U.S. 523W	-0.43	-0.58	-0.80	-1.04	-1.30	-0.83
Neb. 808	-0.38	-0.52	-0.72	-0.87	-0.99	-0.70
P.A.G. SX29	-0.32	-0.42	-0.71	-0.79	-0.91	-0.63
Pio. 321	-0.33	-0.48	-0.68	-0.75	-0.92	-0.63
N.K. KT657	-0.29	-0.45	-0.68	-0.83	-1.06	-0.66
DK XL362	-0.48	-0.56	-0.78	-0.96	-1.10	-0.78
DK 805A	-0.35	-0.49	-0.71	-0.96	-1.09	-0.72
Population mean	-0.37	-0.50	-0.73	-0.89	-1.05	

Table 4. Log W values for Tribune, 1967.

Hybrid	Population 12,000	16,000	20,000	24,000	28,000	Average
U.S. 523W	-0.42	-0.52	-0.69	-0.90	-1.07	-0.72
Neb. 808	-0.36	-0.58	-0.72	-0.88	-0.89	-0.69
P.A.G. SX29	-0.39	-0.61	-0.70	-0.77	-0.92	-0.68
Pio. 321	-0.41	-0.56	-0.68	-0.75	-0.85	-0.65
N.K. KT657	-0.34	-0.53	-0.59	-0.80	-0.80	-0.61
DK XL362	-0.54	-0.56	-0.67	-0.83	-0.91	-0.70
DK 805A	-0.45	-0.65	-0.77	-0.91	-1.12	-0.78
Population mean	-0.42	-0.57	-0.69	-0.84	-0.94	

Table 5. Log W values for Tribune, 1968.

Hybrid	Population 12,000	16,000	20,000	24,000	28,000	Average
U.S. 523W	-0.51	-0.68	-0.77	-0.95	-1.11	-0.81
Neb. 808	-0.44	-0.61	-0.77	-0.90	-1.04	-0.75
P.A.G. SX29	-0.39	-0.58	-0.74	-0.85	-1.03	-0.72
Pio. 321	-0.38	-0.58	-0.71	-0.99	-1.08	-0.75
N.K. KT657	-0.47	-0.61	-0.81	-0.90	-1.05	-0.77
DK XL362	-0.64	-0.74	-0.84	-0.95	-1.24	-0.88
DK 805A	-0.56	-0.68	-0.86	-1.06	-1.27	-0.89
Population mean	-0.48	-0.64	-0.79	-0.94	-1.12	

Table 6. Log W values for Scandia, 1966.

Hybrid	Population 12,000	16,000	20,000	24,000	28,000	Average
U.S. 523W	-0.40	-0.52	-0.64	-0.83	-0.78	-0.63
Neb. 808	-0.49	-0.62	-0.73	-0.88	-0.97	-0.74
P.A.G. SX29	-0.37	-0.58	-0.68	-0.78	-0.90	-0.66
Pio. 321	-0.47	-0.65	-0.70	-0.88	-0.99	-0.74
N.K. KT657	-0.44	-0.63	-0.86	-0.96	-1.18	-0.82
DK XL362	-0.88	-1.03	-1.15	-1.16	-1.32	-1.11
DK 805A	-0.58	-0.91	-1.19	-1.53	-1.67	-1.18
Population mean	-0.52	-0.70	-0.85	-1.00	-1.12	

Table 7. Log W values for Scandia, 1967.

Hybrid	Population 12,000	16,000	20,000	24,000	28,000	Average
U.S. 523W	-0.40	-0.48	-0.70	-0.86	-1.06	-0.70
Neb. 808	-0.29	-0.47	-0.61	-0.70	-0.82	-0.58
P.A.G. SX29	-0.32	-0.46	-0.56	-0.74	-0.81	-0.58
Pio. 321	-0.37	-0.43	-0.61	-0.76	-0.92	-0.62
N.K. KT657	-0.40	-0.46	-0.60	-0.76	-0.91	-0.63
DK XL362	-0.56	-0.62	-0.71	-0.87	-1.00	-0.75
DK 805A	-0.40	-0.55	-0.73	-0.90	-1.13	-0.74
Population mean	-0.39	-0.50	-0.65	-0.80	-0.95	

Table 8. Log W values for Scandia, 1968.

Hybrid	Popualtion 12,000	16,000	20,000	24,000	28,000	Average
U.S. 523W	-0.54	-0.73	-0.95	-1.22	-1.33	-0.95
Neb. 808	-0.61	-0.73	-0.90	-1.07	-1.17	-0.90
P.A.G. SX29	-0.61	-0.78	-0.97	-1.10	-1.24	-0.94
N.K. KT657	-0.62	-0.83	-0.93	-1.12	-1.27	-0.95
DK XL362	-0.91	-0.94	-1.04	-1.15	-1.36	-1.08
DK 805A	-0.65	-0.85	-1.03	-1.17	-154	-1.05
Population mean	-0.66	-0.81	-0.97	-1.13	-130	

Table 9. U.S. 523W yields per acre by population for Colby, Tribune, and Scandia, Kansas 1966-68.

Location and year		12,000	16,000	20,000	24,000	28,000	Average
Colby	1967	136	142	140	120	126	133
	1968	132	135	147	124	113	130
Tribune	1966	142	160	159	150	134	149
	1967	144	163	167	173	151	160
	1968	128	146	160	165	166	153
Scandia	1966	151	170	185	178	156	168
	1967	143	177	177	186	173	171
	1968	124	139	138	126	132	132
Population mean		122	154	159	153	144	150

Table 10. Nebraska 808 yields per acre by population for Colby, Tribune, and Scandia, Kansas 1966-68.

Location and year		12,000	16,000	20,000	24,000	28,000	Average
Colby	1967	168	157	165	168	165	165
	1968	133	158	155	147	159	150
Tribune	1966	144	177	170	174	180	169
	1967	143	163	165	167	175	163
	1968	137	156	165	167	168	158
Scandia	1966	124	154	168	178	168	158
	1967	159	180	193	218	219	194
	1968	116	139	143	146	152	139
Population mean		140	160	160	171	173	162

Table 11. P.A.G. SX29 yields per acre by population for Colby, Tribune, and Scandia, Kansas 1966-68.

Location and year		12,000	16,000	20,000	24,000	28,000	Average
Colby	1967	163	176	185	192	167	176
	1968	140	153	146	145	145	146
Tribune	1966	155	188	176	191	194	181
	1967	149	169	178	184	181	172
	1968	145	161	170	178	175	166
Scandia	1966	124	167	177	188	176	166
	1967	152	181	204	209	221	194
	1968	116	132	135	142	145	134
Population mean		156	166	184	179	176	167

Table 12. Pioneer 321 yields per acre by population for Colby, Tribune, and Scandia, Kansas 1966-68.

Location and year		12,000	16,000	20,000	24,000	28,000	Average
Colby	1967	160	160	174	177	180	170
	1968	131	143	149	151	146	144
Tribune	1966	158	178	181	192	191	180
	1967	144	163	172	184	186	170
	1968	146	161	171	165	170	162
Scandia	1966	140	155	172	176	128	154
	1967	148	186	193	205	200	186
	1968	111	129	136	139	146	132
Population mean		142	159	168	174	168	162

Table 13. Northrup King KT657 yields per acre by population for Colby, Tribune, and Scandia, Kansas 1966-68.

Location and year		12,000	16,000	20,000	24,000	28,000	Average
Colby	1967	167	172	183	181	162	173
	1968	132	144	144	143	134	139
Tribune	1966	157	180	179	185	166	174
	1967	153	171	191	192	198	181
	1968	135	160	159	166	171	158
Scandia	1966	140	156	152	162	128	148
	1967	143	181	194	207	200	185
	1968	114	126	141	139	140	132
Population mean		143	161	168	172	169	161

Table 14. DeKalb XL362 yields per acre by population for Colby, Tribune, and Scandia, Kansas 1966-1968.

Location and year		12,000	16,000	20,000	24,000	28,000	Average
Colby	1967	131	160	168	177	158	159
	1968	118	147	146	144	146	140
Tribune	1966	132	159	163	164	159	155
	1967	124	156	169	171	169	158
	1968	113	143	155	162	144	143
Scandia	1966	96	100	111	130	120	111
	1967	119	154	175	185	184	163
	1968	86	112	127	135	127	117
Population mean		115	141	152	158	151	143

Table 15. DeKalb 805A yields per acre by population for Colby, Tribune, and Scandia, Kansas 1966-68.

Location and year		12,000	16,000	20,000	24,000	28,000	Average
Colby	1967	141	162	158	143	150	151
	1968	129	150	165	152	166	152
Tribune	1966	148	176	170	165	154	163
	1967	136	141	154	156	135	144
	1968	122	141	148	153	138	140
Scandia	1966	128	116	108	95	88	107
	1967	140	165	171	170	163	162
	1968	111	123	128	130	107	120
Population mean		132	147	150	146	138	142

PREDICTING OPTIMUM CORN POPULATIONS FOR CORN GROWN UNDER IRRIGATION IN KANSAS

by

LOWELL ALAN BURCHETT

B. S., Oklahoma State University, 1956

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

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A study was conducted to investigate certain characteristics of corn (Zea mays L.) grown under irrigation in Kansas. Two specific objectives were (1) to determine if a linear relationship exists between the logarithm of the grain yield per plant and the number of plants per unit land area and (2) to determine if the use of the exponential model would adequately predict optimum plant population for a given hybrid.

Data were taken from a hybrid population study at three irrigated locations, Colby, Tribune and Scandia for the years 1966, 1967 and 1968, except for Colby, 1966. Seven high yield potential commercial hybrids were grown at populations of 12, 16, 20, 24 and 28 thousand plants per acre. All tests were grown in 30 inch rows, and were replicated four times.

The hybrids were chosen on the basis of performance from the Kansas corn performance tests to represent a variety of characteristics including maturity, prolificacy, type of cross, disease resistance and stalk strength. The hybrids were U.S. 523W, a prolific, white, double cross full season hybrid; P.A.G. Sx29, a yellow single cross of medium maturity with a fairly high optimum population and very high yield potential; Pioneer 321, a yellow double cross that produces well at moderate to high population; Northrup King KT657, a yellow double cross of medium maturity range; DeKalb XL362, a medium early 3-way hybrid that performs best at high populations; DeKalb 805A, a yellow single cross of medium to medium early maturity that performs best at lower populations.

Individual plot yields were calculated on a yield per-plant basis for each population. A logarithmic transformation (base e) for each per-plant yield, log W, was programmed into the computer output. These log W values were subsequently used in regression analyses to test for linearity and predictive value. The mean log W values were also plotted to permit simultaneous visual comparisions and to get general relationships in mind that might help characterize the features under investigation.

Linearity was concluded to exist on the basis of (1) individual regression analyses in which 52 of 56 tests showed correlation coefficients of -0,90 or above, and (2) visual inspection of the scatter mean log W points about the fitted line. No indication of any consistent curvilinear response was noted.

Covariance analyses were made comparing the individual regression slopes with (1) hybrids combined over location-years, (2) location-years combined over hybrids and (3) hybrids combined by locations over years. Almost all intercepts and slopes were significantly different for tests (1) and (2). All of the slopes for hybrids at Colby were the same for test (3), but several were different at Tribune and Scandia.

No single regression line was indentified that would adequately predict optimum population for hybrid for all location-years. Variations of the log W slopes with changes in yield levels and optimum populations appeared to be somewhat predictable.

Further study of these predictable variations led to the proposal of a new use for the exponential model in interpreting corn performance tests grown at two populations. Examples illustrating the use of the model for Nebraska 808 grown in the corn performance test at Scandia in 1967 and 1968 were presented, showing the fit of the calculated yield curve and the observed yield curve from a five population hybrid population study grown on the same experiment field the same two years.