PREDICTING OPTIMUM PLANTING DENSITIES
FOR CORN, (ZEA MAYS L.) SYNTHETICS

by

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INTRODUCTION

Corn (*Zea mays* L.) is the third ranking crop in world production. Though corn yields are improving, potential is much higher. Maximum yields can be achieved with high yielding corn hybrids or synthetic varieties, high soil productivity, proper soil moisture, proper and timely use of herbicides and insecticides, and planting at optimum plant density (plant population). Optimum plant density for maximum yield for a given hybrid or synthetic variety varies with soil productivity, maturity, soil moisture, and other environmental factors. Water stress and soil fertility are two major components of the environment which frequently limit the expression of grain yield.

Many investigators (5, 7, 14, 16) in the corn belt have reported significant hybrid by density interactions. These interactions may be important factors in determining grain yields. Several other researchers (3, 6, 18, 19, 20) have suggested mathematical equations for predicting optimum plant densities. One advantage of predicting optimum density would be that researchers might be able to test and compare new corn hybrids or synthetics or various fertilizer treatments at optimum densities rather than at an arbitrarily selected density which favors some treatments over others.

This study was conducted with three objectives: (1) to characterize the density response of individual families in two genetically diverse corn populations; (2) to determine if the logarithmic relationship between yield per plant and plant density could be used to select families responsive to high plant density; and (3) to determine if this logarithmic relationship adequately describes the density response of synthetics made up from selected families.

REVIEW OF LITERATURE

Corn Density and Yield Relationship

The corn plant is less capable of adjustment to a poor stand than other cultivated grasses. Therefore, the proper planting rate is essential to obtain maximum production. In the search for higher grain yields of corn, the effect of plant densities and distribution has received much emphasis. The relationship of corn densities to yield has been studied by many investigators for several years. Optimum corn densities for maximum grain yield, grown under different soil productivity, maturity, and moisture conditions ranges from 7.5 thousand plants/ha (7) to 150.0 thousand plants/ha (9).

Dungan, Lang, and Pendleton (7) summarized corn densities and soil productivity research to 1958, and concluded that grain yield increased with higher plant densities up to a particular limit or optimum level above which the yield declined. Optimum corn densities for maximum corn yields are affected by maturity, soil productivity, and moisture, with soil productivity being the major factor determining yields.

Stickler and Walter (14) measured the performance of corn hybrids of varying maturity at four plant densities and three productivity levels. Yields were significantly affected by plant densities in ten of eleven trials. They found significant hybrid x maturity x density interactions in nearly all tests. Early hybrids responded most to high plant density and yielded 45% more than full-season hybrids at the high density and low productivity level. At low stand density, the early hybrids were lower in grain yield than either mid-season or full-season hybrids. In contrast, full-season hybrids yielded lowest at high density. They reported that with increasing productivity, all hybrids were more responsive to increased plant density. Yield components, ear weight and number of ears per 100 plants, were reduced at high densities at the low productivity level. However, ear weight and ear number were less affected at high plant density in short-season hybrid than in full-season hybrid.

Vanderlip (16) reported significant hybrid by density interaction at several locations in Kansas, especially at higher yield levels. He observed that the optimum plant densities for maximum yields were different for eight hybrids tested at various locations. In general, maximum yields were obtained from 50 to 60 thousand plants/ha. Yield declined above 60 thousand plants/ha and some of the hybrids declined more rapidly in yield with 70 thousand plants/ha. Ear weight per plant and ear number decreased with increasing plant densities. Lodging and shelling percentage increased with increasing plant densities and highest lodging was observed at 70 thousand plants/ha. However, maturity of these hybrids was not affected by plant density.

Colville, et al. (5) studied six corn hybrids of varying maturity at 30, 40, 50 and 60 thousand plants/ha at three productivity levels in a total of ten irrigated experiments in Nebraska. The optimum density for maximum yield for the two early hybrids was 60 thousand plants/ha. The full-season hybrids had the optimum plant density of 40 to 50 thousand plants/ha. At lower productivity levels, the differential in responses by hybrids to density increases were relatively smaller than those observed at higher productivity levels. They reported significant hybrid by density interactions at several locations in Nebraska, especially at higher yield levels.

Termude, Shank, and Dirks (15) from South Dakota tested eight commercial hybrids of varying maturity at seven plant densities (10 to 80 thousand plants/ha). They reported significant hybrid by density interactions at several locations in South Dakota. Highest yields were obtained at 30 to 40 thousand plants/ha. Corn hybrids of different maturity responded differently to high plant densities; usually, short-season hybrids were more responsive to high plant densities than full-season hybrids (7, 15, 18).

Rutger and Crowder (13) evaluated six hybrids of varying maturity at 40, 50, 60, 70 and 80 thousand plants/ha. The hybrids differed in response to density for grain yield and ears per 100 plants. The hybrids most responsive to high plant densities had more ears per 100 plants at high plant densities. A significant hybrid by density interaction for grain yield was observed. Optimum plant density for maximum grain yield was 70 thousand plants/ha, with an average ear weight of 127 g.

Goldsworthy, Palmer, and Sperling (9) examined the effect of plant densities on yield and yield components of tropical lowland corn varieties at three plant densities (50 thousand to 150 thousand plants/ha) in Mexico. They reported that grain size decreased with increased plant density, but the effect on yield was small compared with differences in the number of grains. Therefore, the increase in grain yield with increase in plant density was accounted for mainly by an increase in the number of grains/m^2. Lodging increased significantly with increased plant density and was highest at 150 thousand plants/ha.

Relationship between plant density and plant yield.

Generally weight of grain per plant decreases as plant density increases. The relationship between plant density and plant yield has been studied by several investigators for many years.

Duncan (6) reported that for corn grown under midwest conditions, there exists a linear relationship between the logarithm of grain yield per plant and the number of plants per unit area. In addition, he indicated the possibility of utilizing this relationship in variety trials and fertilizer experiments to calculate the optimum plant density for maximum yields. Duncan further explained that the advantage in doing this is that hybrids, varieties, or fertilizer treatments could then be compared on the basis of their highest yielding or optimum densities, rather than at some arbitrarily selected density which favored some and handicapped others.

Carmer and Jackobs (3) observed linear logarithmic relationships between plant density and the yield of grain for seven of eight corn hybrids tested over a range of four plant densities. They proposed an exponential statistical model for predicting optimum density and maximum yields for corn hybrids using this linear relationship.

Dungan et al. (7), Stickler and Walter (14), Vanderlip (16), and Goldsworthy et al. (9) have shown that the yield of grain per plant decreased progressively as plant density increased. Colville (4) found that yield components were linearly correlated with plant density but not with yield due to curvilinear relationship of grain yield to density.

Fery and Janick (8), Brown et al. (2) and Major et al. (11, 12) also observed linear logarithmic relationships between plant populations and plant yield for corn varieties. They used the linear logarithmic function for predicting optimum plant density for maximum yield.

Warren (19) reported more satisfactory linear regression on untransformed yields, but he used number of ears per unit land area rather than grain weight per plant or per unit area as a measure of yield. The linear relations used in this trial were deficient at high densities, however, since they estimated negative numbers of ears per plant. He also reported a good fit of quadractic equation to his sweet corn data.

Willey and Heath (20), reviewing the relationship between plant density and crop yield, described more than twenty-five mathematical functions used by many research workers for yield/density relationships of various crops. They reported that the linear logarithmic equation can fit parabolic yield versus density data. The corn data are of particular interest, because this crop usually displays a very distinct decline in yield at high densities and the yield curve does not cut the density axis but, more realistically, only gradually approaches it. However, they suspected the validity of this equation at very low densities, because the equation cannot allow for a levelling off in yield per plant at densities too low for competition to occur.

Burchett (1) observed linear logarithmic relationships between plant density and plant yield for seven commercial corn hybrids grown at five plant densities at several locations under irrigation in Kansas for three years. Voldeng and Blackman (17, 18) reviewed the relationship between plant density and plant yield. They compared four mathematical functions by fitting their data to these four equations for predicting the optimum plant densities for maximum yields. They reported that linear logarithmic and inverse quadratic functions fit the observed data satisfactorily. They further mentioned that if the linear logarithmic functions can be shown to have general applicability for the prediction of corn grain production within diverse genotypes, then the plant breeder and agronomist would need to test corn hybrids at only two plant densities in order to evaluate their potential maximum yields.

MATERIALS AND METHODS

One-hundred families each of two white corn synthetics, Kansas Drought Synthetic (KDS) and Mex Mix (MM), were planted at plant densities of 30, 55 and 80 thousand plants/ha in 75cm rows at the Ashland Agronomy Farm, Manhattan, on May 7, 1974. Plots were two tows 5m long, replicated two times. The experimental design was a split plot with plant densities as main plots and families as subplots. Data on yield per plant and grain yields were taken from shelled grain of ten competitive plants per plot artificially dried to 11% moisture content.

KDS is a temperate corn synthetic developed from several Cornbelt, drought-tolerant inbred lines in the Kansas State University corn breeding program. KDS is a mid-season synthetic with medium height and ear placement. It is well adapted to Kansas, is heat and drought tolerant, and performs well at 55 to 60 thousand plants/ha.

MM is a synthetic developed from a mixture of many varieties from forty-seven countries and contains temperate, subtropical and mostly tropical germ glasm. Selection for plant height, yield, and maturity has been done in Mexico at the CIMMYT experiment station at Poza Rica. It is a full-season synthetic, well adapted to Mexico; plants are tall with medium-high ear placement and perform well at 50 to 55 thousand plants/ha. Five new synthetics were developed from each of the two basic populations by selecting the ten best families for high density, wide adaptation based on yield efficiency (grain yield per unit leaf area), and specific site adaptation for Manhattan and St. John.

Remnant seed of the selected ten half-sib families of each synthetic were recombined into new synthetics at Tlaltizapan, Mexico, during October 1974-April 1975. These five new synthetics and the original synthetic of each of the two synthetics were planted at densities of 30.0, 42.5, 55.0, 67.5 and 80.0 thousand plants/ha in 75-cm rows at Manhattan on May 1 and at St. John on May 10, 1975. Plots were two rows 5m long, replicated four times. The experimental design was a split plot with plant densities as main plots and synthetics as subplots. Uniform applications of water, fertilizer, herbicides, and insecticides were made in all density treatments. Two seeds per hill were hand planted and thinned to one plant per hill at the five-leaf stage. Data on grain yield per plant were taken by harvesting ears from the two-row plot (except the end plants). Yield data were obtained on the basis of shelled grain weights adjusted to 15.5% moisture content.

Statistical Procedures:

A logarithmic transformation (base 10) of the grain yield per plant (W) was made for the 1974 and 1975 data. Log W values of each of the 100 families of the two synthetics were regressed on plant density. Combined analyses of the five new synthetics were performed. The third series of regression analyses were performed on the new and the original synthetics tested at Manhattan and St. John in 1975.

RESULTS AND DISCUSSION

The main objective of the study was to characterize the density response of individual families in two diverse corn populations on the basis of linear logarithmic relationship between yield per plant and density, and to determine if this linear logarithmic relationship between yield per plant and plant density could be used to select families responsive to high density. In addition, the study was conducted to determine if this logarithmic relationship adequately describes the density response of synthetics made up from selected families.

MANHATTAN

Simple linear regression analyses were performed on the log W values for individual families of KDS and Mex Mix corn populations, Manhattan, 1974. (Appendix Table 6.)

Combined regression analyses (of the ten selected families) for each of the five new synthetics selected for high density (K-6, M-6), wide adaptation No. 1 (K-4, M-4), based on yield per plant (YP) and yield efficiency (grain yield per unit leaf area), wide adaptation No. 2 (K-5, M-5) based on yield efficiency (YE), and coefficient of variation (CV), specific site adaptation for Manhattan (K-1, M-1) and St. John (K-2, M-2), and the original populations (K-0, M-0 based on 100 families) of each population are presented in Table I. Regression analyses for the new synthetics and the original showed highly significant negative correlation coefficients, indicating linear logarithmic relationship between yield per plant and plant density.

Shallow slopes of the regression lines (-0.00185, -0.00176) for high density synthetics K-6 and M-6 showed a clear theoretical, high density response over the original K-0 and M-0 populations with regression coefficients values of -0.00417 and -0.00510, respectively. Figs. 1 and 2 show the regression lines for the high density synthetics and the original populations. As plant density increased from 30 thousand to 80 thousand plants/ha, yield per plant decreased linearly with each increment of plant density. However, the reduction in plant yield with increasing plant density was comparatively less in the high density synthetics than in the original populations.

In 1975 at Manhattan, the high density synthetics (K-6 and M-6) did not respond favorably to high density and the yield per plant was comparatively more affected at high density than the original (K-0, M-0) populations (Table 2). However, the logarithm yield per plant for all synthetics was negatively and highly significantly correlated to plant densities, confirming the findings of Burchett (1), Duncon (6), and Voldeng and Blackman (18).

Table 1. Regression analyses for selected families of KDS and Mex Mix, Manhattan, 1974.

Population							
KDS, Manhattan, 1974				Mex-Mix, Manhattan, 1974			
Synthetic	Calculated intercept (a)	Slope (b)	Correlation coefficient (r)	Synthetic	Calculated intercept (a)	Slope (b)	Correlation coefficient (r)
K-0	2.21054	-0.00417	-0.63090**	M-0	2.14990	-0.00510	-0.56285**
K-1	2.25367	-0.00439	-0.66598**	M-1	2.21342	-0.00456	-0.61391**
K-2	2.18776	-0.00346	-0.56797**	M-2	2.15334	-0.00551	-0.61661**
K-4	2.23805	-0.00392	-0.66528**	M-4	2.20653	-0.00439	-0.62924**
K-5	2.21971	-0.00451	-0.43122**	M-5	2.21339	-0.00434	-0.63836**
K-6	2.12808	-0.00185	-0.40445**	M-6	2.05010	-0.00176	-0.30538*

** Statistically significant at 1% level.
* Statistically significant at 5% level.

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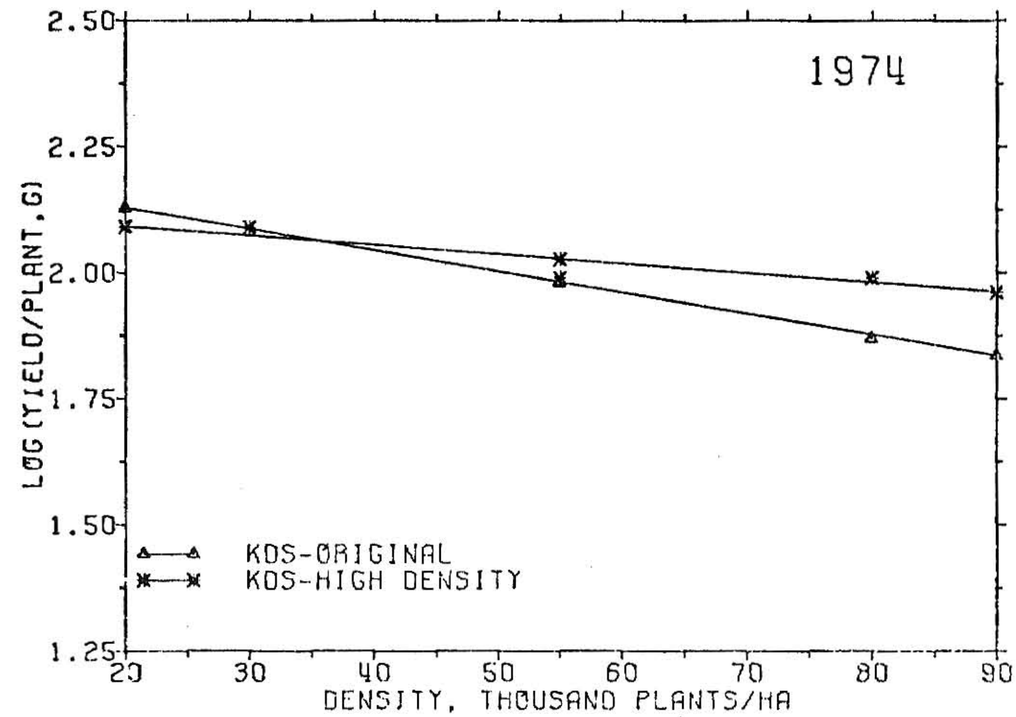

Fig. 1. Fitted regression lines and mean log W points for parental families of KDS-high density synthetic and the original population. Manhattan.

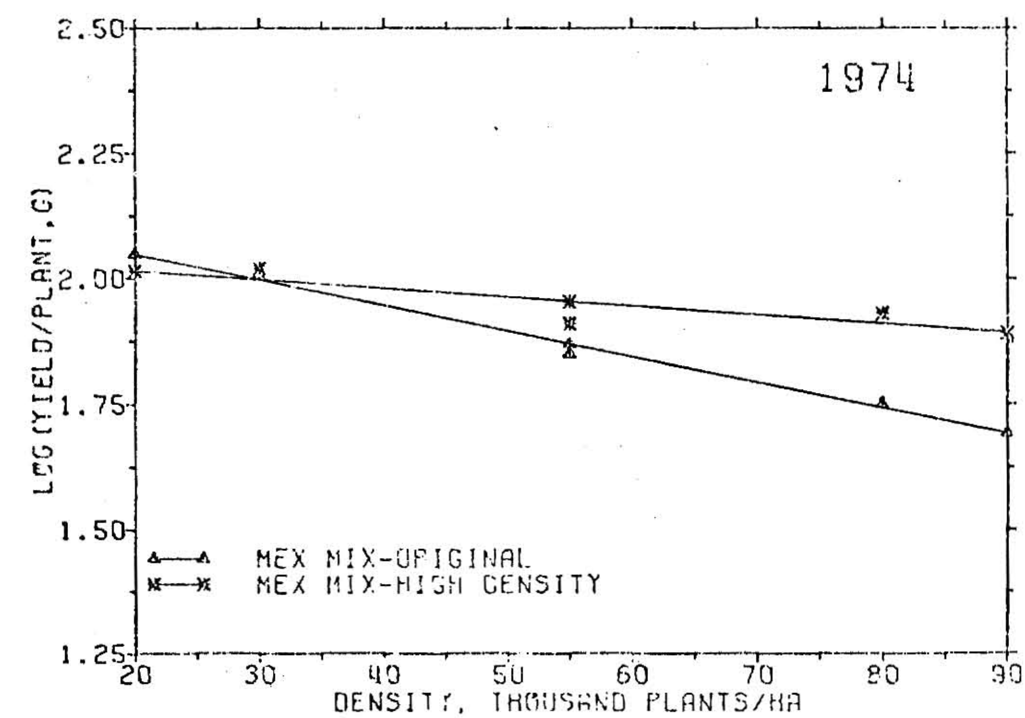

Fig. 2. Fitted regression lines and mean log W points for parental families of Mex-Mix-high density synthetic and original population. Manhattan.

Figs. 3 and 4 show the regression lines and log yield per plant data points for each synthetic. Calculated intercepts were higher for the high density synthetics than for the original populations. However, the yield per plant dropped comparatively more rapidly with increasing density for the high density synthetics than for the original populations. The synthetic x density interactions for log yield per plant and grain yields were highly significant for Manhattan 1974 (Appendix Table 13), and indicated a differential response to plant density. The non-significant synthetic x density interactions for log yield per plant and grain yields for Manhattan 1975 suggested that all synthetics (original and new synthetics) responded similarly to plant densities. However, yield per plant was significantly affected by density and synthetics and grain yield by synthetics only (Appendix Table 14).

ST. JOHN

Considerable lodging occurred due to South Western corn borer in 1975 at St. John, causing comparatively lower yields in KDS and Mex Mix synthetics. Yield per plant decreased with increasing plant density from 30 thousand to 80 thousand plants/ha. Log yield per plant was negatively and highly significantly correlated to plant density in all synthetics tested. Slopes of the regression lines for K-6, -0.00865 and M-6, -0.00930

Table 2. Regression analyses for KDS and Mex Mix, Manhattan, 1975.

Population							
KDS, Manhattan, 1975				Mex-Mix, Manhattan, 1975			
Synthetic	Calculated intercept (a)	Slope (b)	Correlation coefficient (r)	Synthetic	Calculated intercept (a)	Slope (b)	Correlation coefficient (r)
K-0	2.46995	-0.00740	-0.71048**	M-0	2.36370	-0.00794	-0.81827**
K-1	2.60440	-0.00980	-0.93041**	M-1	2.45015	-0.00764	-0.79617**
K-4	2.53878	-0.00773	-0.82197**	M-4	2.7202	-0.01313	-0.91921**
K-5	2.55680	-0.00950	-0.79913**	M-5	2.53915	-0.00993	-0.85686**
K-6	2.66104	-0.01027	-0.87651**	M-6	2.57866	-0.01129	-0.87927**

** Statistically significant at 1% level.

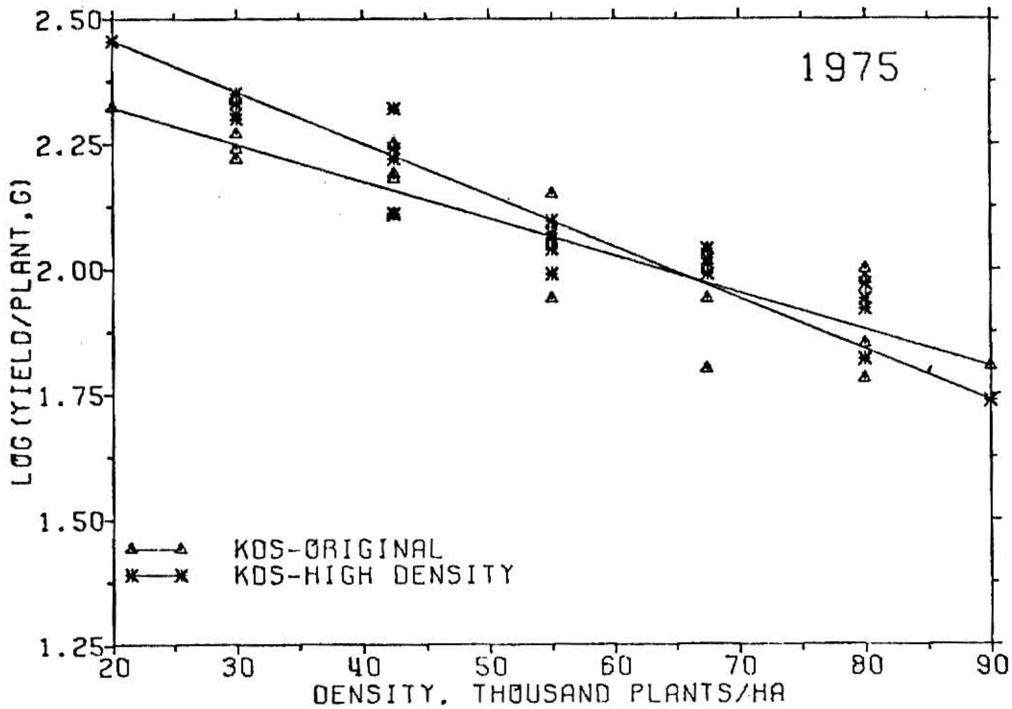

Fig. 3. Fitted regression lines and individual log W points for KDS-high density synthetic and original population, Manhattan

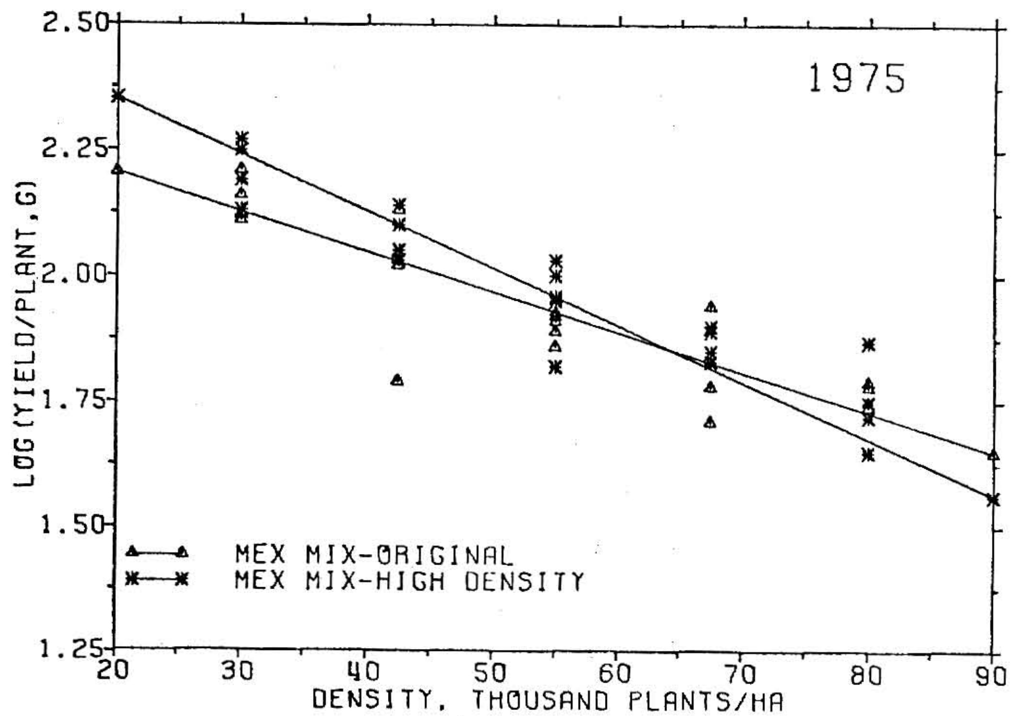

Fig. 4. Fitted regression lines and individual log W points for Mex-Mix-high density and original population, Manhattan.

differed little from the original K-0, -0.00821 and M-0, -0.00915 (Table 3), and indicated that high density synthetics did not respond differently to high plant density. Figs. 5 and 6 show the regression lines and log yield per plant data points for the high density synthetics and the originals. The more scattered points around the regression lines in Mex Mix indicated comparatively more variation in plant yields between replications than KDS corn synthetics.

Response of the KDS high density synthetic was essentially identical to the KDS original. Mex Mix high density synthetic had a higher intercept (2.31195) than Mex Mix original (2.20695) and similar slopes (-0.0093 and -0.00915). Thus, the high density synthetic maintained consistently greater yield per plant at each plant density. The nonsignificant synthetic x density interactions for log yield per plant and grain yield indicated that all synthetics (high density and original) of KDS and Mex Mix tested responded similarly to plant densities. However, the log yield per plant was significantly affected by densities; and grain yields were affected by synthetics in KDS population. In Mex Mix, the log yield per plant was significantly affected by densities and synthetics. Grain yield was affected by synthetics only (Appendix Table 15).

Table 3. Regression analyses for KDS and Mex Mix, St. John, 1975.

Population							
KDS, St. John, 1975				Mex-Mix, St. John, 1975			
Synthetic	Calculated intercept (a)	Slope (b)	Correlation coefficient (r)	Synthetic	Calculated intercept (a)	Slope (b)	Correlation coefficient (r)
K-0	2.46061	-0.00821	-0.83778**	M-0	2.20695	-0.00915	-0.78874**
K-2	2.38643	-0.00786	-0.76553**	M-2	2.24730	-0.01009	-0.76854**
K-4	2.47742	-0.00886	-0.71905**	M-4	2.36589	-0.01042	-0.84108**
K-5	2.34762	-0.00636	-0.71720**	M-5	2.22705	-0.00757	-0.70274**
K-6	2.48722	-0.00865	-0.75116**	M-6	2.31195	-0.00930	-0.75238**

** Statistically significant at 1% level.

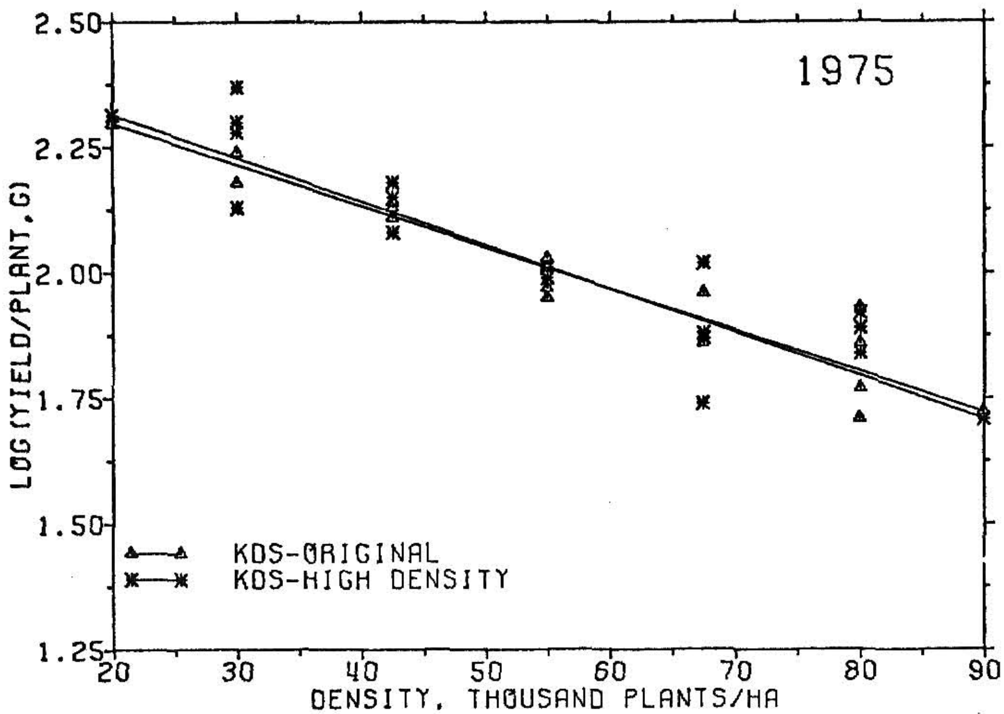

Fig. 5. Fitted regression lines and individual log W points for KDS-high density synthetic and original population, St. John.

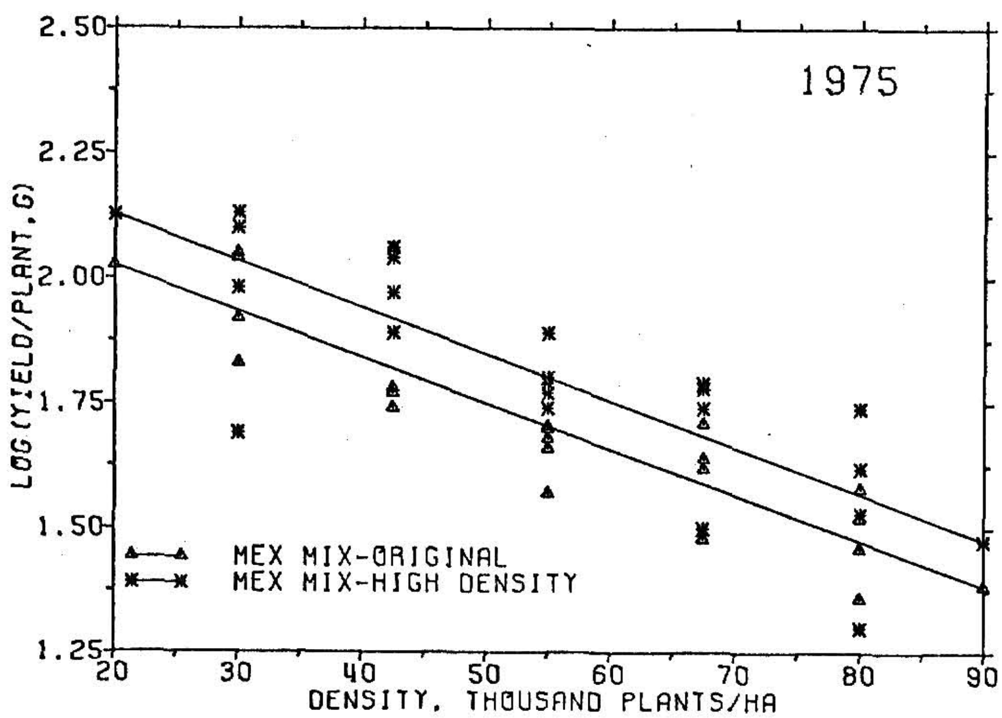

Fig. 6. Fitted regression lines and individual log W points for Mex-Mix-high density synthetic and original population, St. John.

Prediction of Optimum Densities

The third objective of this study was to determine if this linear logarithmic relationship adequately describes the density response of synthetics made up from selected families.

Regression analyses of the 1974 high density synthetics compared with the 1975 regression analyses for Manhattan and St. John (Tables 1-3) showed a considerable range of intercept and slope values for the synthetics. The higher negative regression coefficient values for high density synthetics (K-6, M-6) tested at Manhattan and St. John in 1975 indicated that these synthetics did not respond favorably to high density. The plant yield of high density synthetics was more affected at high density (Appendix Tables 7-8).

Figs. 7 and 8 show the linear regression lines of the logarithm of grain weight per plant on plant density for KDS and Mex Mix synthetics, described in the previous graphs. The flattest slopes of the fitted regression lines for the theoretical high density KDS (K-6) and M-6 synthetics at Manhattan 1974 indicated very high and unrealistic density response. But, in 1975, the high density synthetics were the least responsive to high density (Appendix Tables 11-12). Figs. 9 and 10 clearly demonstrate the comparison of the maximum grain yields and optimum plant densities for high density and original synthetics calculated from the log W data of 1974 and 1975. The high

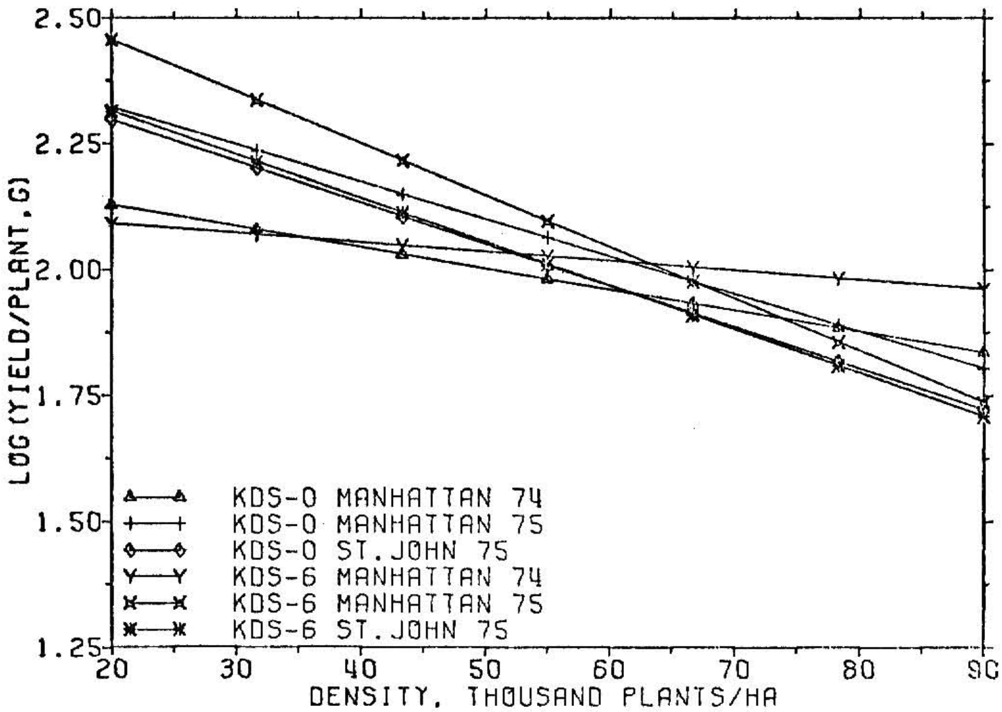

Fig. 7. Comparison of linear regression lines of the log of grain weight/plant on density for parental families of KDS high density synthetic and original population, 1974, vs physically tested KDS-high density synthetics and original populations at Manhattan and St. John, 1975.

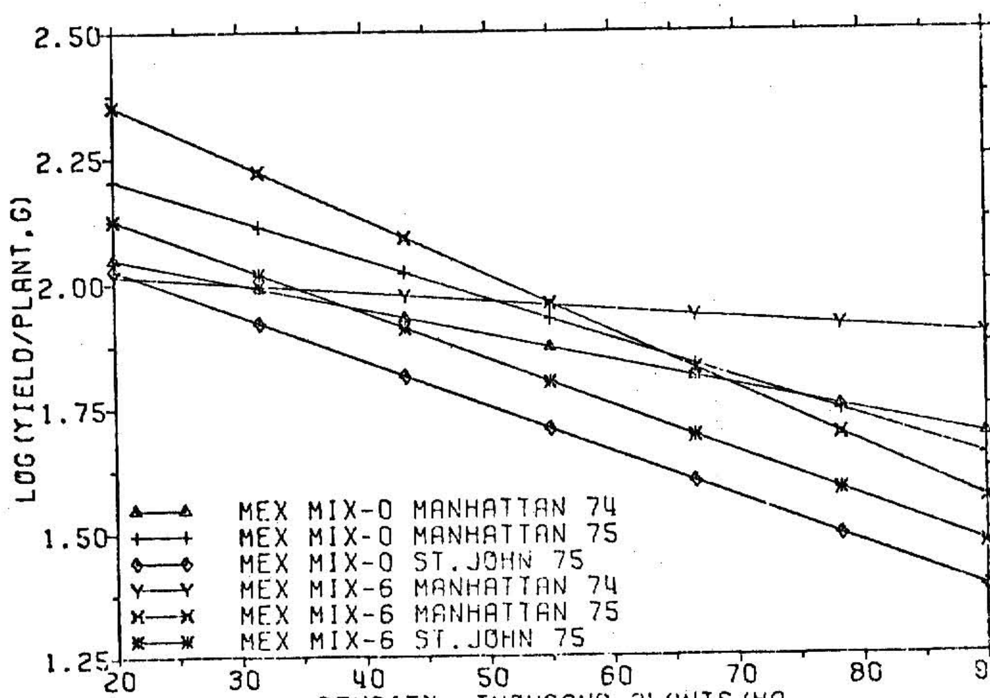

Fig. 8. Comparison of linear regression lines of the log of grain weight/plant on density for parental families of Mex-Mix-high density synthetic and original population, 1974, vs physically tested Mex-Mix-high density synthetics and original populations at Manhattan and St. John, 1975.

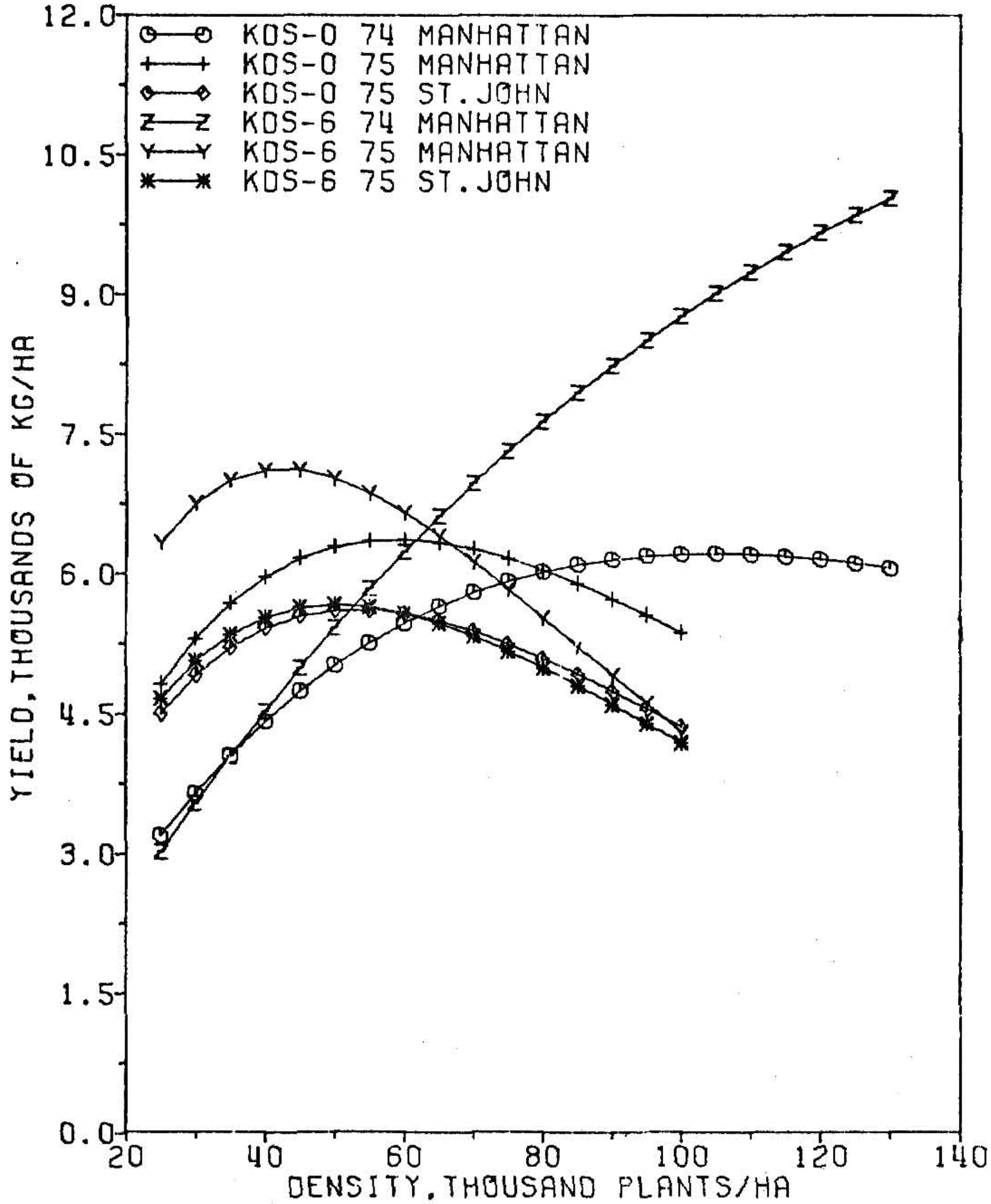

Fig. 9. Comparison of calculated yield curves for parental families of KDS-theoretical high density synthetic and original population, 1974, vs physically tested KDS-high density synthetics and original populations at Manhattan and St. John, 1975.

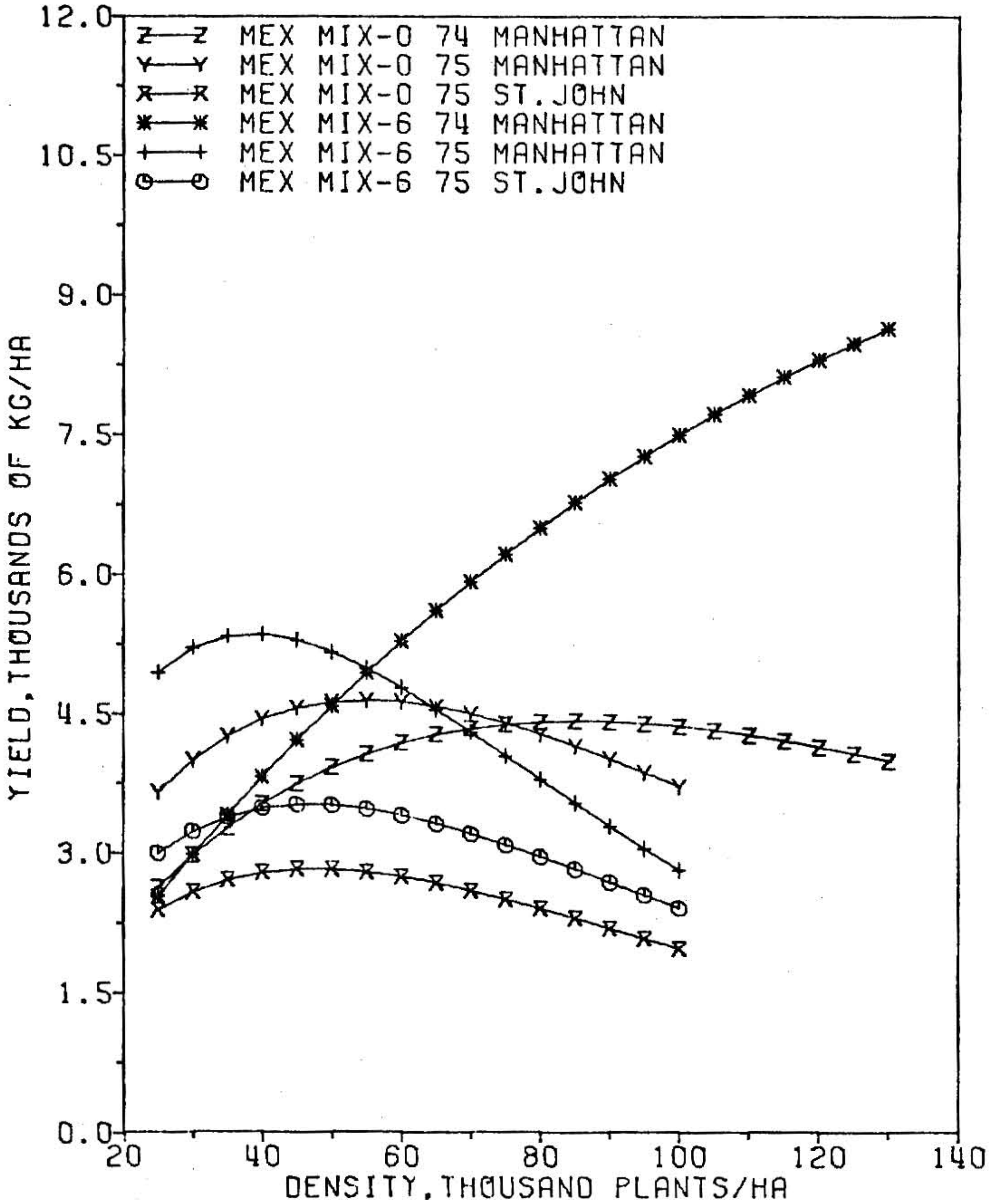

Fig. 10. Comparison of calculated yield curves for parental families of Mex-Mix-theoretical high density synthetic and original population, 1974, vs physically tested Mex-Mix-high density synthetics and original populations at Manhattan and St. John, 1975.

Table 4. Calculated Optimum Planting Density for KDS New Synthetics and Original Population

	1974	1975	1975
Synthetics	Manhattan (parental response)	Manhattan	St. John
K-0	164,130	58,820	52,910
K-1	99,000	44,250	--
K-2	125,000	--	55,250
K-4	111,100	56,180	49,000
K-5	96,150	45,660	68,490
K-6	232,560	42,190	50,250

Table 5. Calculated Optiumum Planting Density for Mex Mix New Synthetics and Original Population

	1974	1975	1975
Synthetics	Manhattan (parental response)	Manhattan	St. John
M-0	85,140	54,650	47,390
M-1	95,240	56,800	--
M-2	78,740	--	43,480
M-4	99,000	33,100	41,670
M-5	100,000	43,670	57,470
M-6	243,390	38,460	46,700

density synthetics, K-6, M-6 and their original K-0 and M-0 populations, predicted optimum densities were very high and unrealistic because (1) the predicted optimum densities, for all synthetics (except M-2), were far beyond the density range studied; (2) they did not agree with calculated optimum densities in 1975 (Tables 4-5).

Possible reason for the greater differences obtained between the two years predicted optimum planting densities for KDS and Mex Mix corn populations could be variation in plot size harvested and the methods of harvesting.

SUMMARY AND CONCLUSIONS

Regression analysis of the ten combined families selected for high density on the basis of logarithm of grain yield per plant and plant density indicated a clear theoretical high density response of KDS and Mex Mix high density synthetics over the original populations. The regression analyses showed highly significant negative correlation values for log yield per plant and plant density.

Predicted optimum densities for KDS and Mex Mix high density synthetics and the original populations based on the linear regression analyses were very high and unrealistic, because (1) calculated optimum densities were far beyond the density range studied, and (2) calculated optimum densities for the theoretical high densities synthetics and their originals in 1974 were very high compared to the optimum densities determined at Manhattan and St. John in 1975.

The theoretical high density KDS and Mex Mix synthetics did not respond more to high plant density as compared to the original populations. However, the logarithm of grain yield per plant was negatively and highly significantly correlated to plant density in all experiments tested at Manhattan and St. John, 1975.

No definite conclusions regarding the very high and unrealistic calculated optimum densities at Manhattan, 1974, and the lack of response of high density synthetics to high plant density at Manhattan and St. John in 1975 can be drawn.

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LITERATURE CITED

1. Burchett, L. A. 1969. Predicting optimum corn populations for corn grown under irrigation in Kansas. M.S. Thesis. Agron. Dept., Kansas State University.

2. Brown, R. H., E. R. Beaty, W. J. Ethredge, and D. D. Hayes. 1970. Influence of row width and plant population on yield of two varieties of corn (*Zea mays* L.) Agron. J. 62:767-770.

3. Carmer, S. G. and J. A. Jackobs. 1965. An exponential model for predicting optimum plant density and maximum corn yield. Agron. J. 57:241-244.

4. Colville, W. L. 1962. Influence of rate and method of planting corn hybrids. Agron. J. 54:297-300.

5. Colville, W. L., A. Drier, D. P. McGill, P. Grabouski, and P. Ehlus. 1964. Influence of plant population, hybrid and "productivity level" on irrigated corn production. Agron. J. 56:332-35.

6. Duncan, W. G. 1958. The relationship between corn populations and yield. Agron. J. 50:82-84.

7. Dungan, G. H., A. L. Lang, and J. W. Pendleton. 1958. Corn population levels in relation to soil productivity. *In* Advances in Agronomy, A. G. Norman, ed. 10:435-473.

8. Fery, R. L. and J. Janick. 1971. Response of corn (*Zea mays* L.) to population pressure. Crop Sci. 11:220-224.

9. Goldsworthy, P. R., A. F. E. Palmer, and D. W. Sperling. 1974. Growth and yield of lowland tropical maize in Mexico. J. Agric. Sci. Camb. 83:223-230.

10. Hunter, R. B., L. W. Kannenberg, and E. E. Gamble. 1970. Performance of five maize hybrids in varying plant populations and row widths. Agron. J. 62:255-256.

11. Major, D. J., R. B. Hunter, L. W. Kannenberg, T. B. Daynard, and J. W. Tanner. 1972. Comparison of inbred and hybrid corn grain yield measured at equal leaf area index. Can. J. of Plant Sci. 53:533-536.

12. Major, D. J., R. B. Hunter, L. W. Kannenberg, and J. W. Tanner. 1973. Effect of population density on the relationship between inbred and single crosses yield performance of corn. Can. J. of Plant Sci. 53:533-536.

13. Rutger, J. N. and L. V. Crowder. 1967. Effect of high plant density on silage and grain yields of six corn hybrids. Crop Sci. 7:182-184.

14. Stickler, F. C. and T. L. Walter. 1965. Corn production as affected by plant population and hybrids of varying maturity. Trans. Kansas Acad. Sci. Vol. 68:508-515.

15. Termunde, D. E., D. B. Shank, and V. A. Dirks. 1963. Effects of population levels on yields and maturity of maize hybrids grown on the northern great plains. Agron. J. 55:551-555.

16. Vanderlip, R. L. 1968. How plant populations affect yields of corn hybrids. Kansas Agri. Expt. Sta. Bull. 519.

17. Voldeng, H. D. and G. E. Blackman. 1974. Interactions between genotype and density on yield components of Zea mays L. I. Production of dry matter by the Shoot. J. of Agric. Sci. Camb. 83:189-196.

18. Voldeng. H. D. and G. E. Blackman. 1975. Interactions between genotype and density on the yield components of Zea mays L. II. Grain production. J. Agric. Sci. Camb. 84:61-74.

19. Warren, J. A. 1963. Use of empirical equations to describe the effects of plant density on yield of corn and the application of such equations to variety evaluation. Crop Sci. 3:197-201.

20. Willey, R. W. and Heath, S. B. 1969. Quantitative relationship between plant population and crop yield. In Advances in Agron., N. C. Brady, ed. 21:281-321.

APPENDIX

Table 6. Regression analyses for KDS and Mex Mix families, Manhattan, 1974.

Family	a	b	r	Synthetic	Family	a	b	r	Synthetic
1	2.19416	-0.0054	-0.64229		1	2.39642	-0.00707	-0.96050	M1, M4, M5
2	2.37293	-0.00713	-0.89943		2	2.28590	-0.00693	-0.84582	M1, M2, M5
3	2.23165	-0.00418	-0.77654		3	2.10902	-0.00488	-0.66097	
4	2.29303	-0.00478	-0.80958		4	2.05325	-0.00542	-0.85459	M2
5	2.11203	-0.00274	-0.54942	K2	5	2.19181	-0.00589	-0.79027	
6	2.13549	-0.00226	-0.44969		6	2.30110	-0.00861	-0.89308	
7	2.24812	-0.00397	-0.76545	K2	7	2.17766	-0.00629	-0.90705	
8	2.24777	-0.00506	-0.70910		8	1.99019	-0.00372	-0.71518	
9	2.27212	-0.00387	-0.80457	K2, K4	9	2.51392	-0.01224	-0.90782	
10	2.26486	-0.00440	-0.76279		10	2.23798	-0.00890	-0.94133	
11	2.35256	-0.00776	-0.92722		11	2.26581	-0.00666	-0.90505	
12	2.30449	-0.00578	-0.66816	K5	12	2.19684	-0.00554	-0.72052	
13	2.26588	-0.00414	-0.91572		13	1.60930	-0.00293	-0.34923	
14	2.36372	-0.00621	-0.92590		14	2.28706	-0.01152	-0.75308	
15	2.24631	-0.00386	-0.65485	K1, K4	15	2.28525	-0.00497	-0.89161	M1, M5
16	2.29871	-0.00598	-0.86408		16	2.12097	-0.00217	-0.55431	M4, M5
17	2.07779	-0.000989	-0.21707	K6	17	1.95825	-0.000963	-0.28237	M6
18	2.14317	-0.00241	-0.54440		18	2.20107	-0.00598	-0.73591	M2
19	2.17289	-0.00385	-0.68669		19	2.26490	-0.00547	-0.92749	
20	2.20127	-0.00446	-0.62967		20	2.0652	-0.00284	-0.46833	
21	2.34659	-0.00685	-0.85711	K2	21	2.29940	-0.00683	-0.92411	
22	2.21853	-0.00334	-0.67786	K1, K4, K5	22	2.46619	-0.01052	-0.82919	
23	2.09729	-0.00199	-0.45452	K6	23	2.24523	-0.00506	-0.83308	
24	2.15253	-0.00313	-0.49236	K6	24	1.81688	0.000814	0.19629	M6
25	2.28982	-0.00519	-0.86834	K1	25	2.19901	-0.00653	-0.78123	

Table 6. Regression analyses for KDS and Mex Mix families, Manhattan, 1974.

KDS, Manhattan, 1974					Mex-Mix, Manhattan, 1974				
Family	a	b	r	Synthetic	Family	a	b	r	Synthetic
26	2.43586	-0.00855	-0.78723	K1	26	2.18798	-0.00551	-0.96699	M4
27	2.21362	-0.00320	-0.73134	K1	27	2.12080	-0.00463	-0.78861	
28	1.88941	0.000205	0.03390		28	2.29383	-0.00720	-0.97329	
29	2.1974	-0.00489	-0.73553		29	1.92602	-0.00410	-0.67551	
30	2.17461	-0.00321	-0.65525	K1	30	1.4556	0.00330	0.26450	
31	2.08289	-0.00225	-0.55803		31	2.24837	-0.00748	-0.82430	
32	2.20612	-0.00262	-0.82363	K4, K6	32	2.29456	-0.00924	-0.88445	
33	2.02596	-0.00044	-0.29925	K4	33	2.29800	-0.00846	-0.74089	M2
34	1.95467	0.00037	0.08082		34	2.17356	-0.00531	-0.64656	
35	2.08759	-0.00257	-0.61713		35	1.95254	-0.00379	-0.71657	M2
36	2.31042	-0.00534	-0.89925		36	2.15699	-0.00529	-0.70832	
37	2.06721	-0.000871	-0.19224	K6	37	2.02956	-0.00145	-0.46087	M1, M6
38	2.29190	-0.00674	-0.89307		38	2.24007	-0.00657	-0.65968	
39	2.35596	-0.0061	-0.87320		39	2.2370	-0.00422	-0.76144	M4, M6
40	2.1436	-0.00309	-0.84232		40	2.06525	-0.00430	-0.59792	
41	2.14917	-0.00304	-0.75753		41	2.17221	-0.00490	-0.87667	M5
42	2.07117	-0.00067	-0.18162	K1, K6	42	2.17020	-0.00460	-0.62754	
43	2.13380	-0.00243	-0.81422		43	1.92701	-0.00293	-0.46520	
44	2.22653	-0.0051	-0.71386		44	2.4733	-0.01357	-0.94757	
45	2.0675	-0.00262	-0.44066		45	2.1985	-0.00409	-0.91409	
46	2.27982	-0.00465	-0.89979	K2, K4	46	2.19363	-0.00578	-0.80492	
47	2.12778	-0.00264	-0.83625		47	2.36097	-0.00848	-0.89870	
48	2.21290	-0.00327	-0.64865	K4, K6	48	2.10802	-0.00441	-0.61747	

Table 6. Regression analyses for KDS and Mex Mix families, Manhattan, 1974.

KDS, Manhattan, 1974					Mex Mix, Manhattan, 1974				
Family	a	b	r	Synthetic	Family	a	b	r	Synthetic
49	2.21494	-0.00521	-0.81768		49	2.26916	-0.00556	-0.74977	
50	2.34002	-0.00632	-0.88871	K4	50	2.09114	-0.00411	-0.54956	
51	2.31744	-0.00537	-0.7240		51	2.10679	-0.00359	-0.38949	M1, M4, M5
52	2.33699	-0.00754	-0.9377		52	2.29071	-0.00730	-0.97263	
53	2.2599	-0.00517	-0.96428	K2	53	2.26389	-0.00777	-0.79619	M1
54	2.33754	-0.00574	-0.75686		54	2.19220	-0.00515	-0.75129	
55	2.49505	-0.00985	-0.87285	K5	55	2.19163	-0.00444	-0.67119	
56	2.2708	-0.00480	-0.95008		56	2.16298	-0.00318	-0.58192	
57	2.25311	-0.00443	-0.74329		57	1.86848	-0.00140	-0.15762	
58	2.34036	-0.00521	-0.82402		58	2.07890	-0.00422	-0.81482	
59	2.07544	-0.00244	-0.58356		59	2.30499	-0.00772	-0.84248	
60	2.17305	-0.00242	-0.70424	K2,K5, K6	60	2.21343	-0.01063	-0.67424	
61	2.31556	-0.00525	-0.91483	K2	61	1.78854	-0.00226	-0.30126	M2, M6
62	2.41943	-0.00820	-0.81042	K1, K4	62	2.11576	-0.00306	-0.75593	
63	2.1345	-0.00429	-0.79822		63	2.2047	-0.00914	-0.66343	
64	2.01946	-0.00227	-0.39556		64	2.0154	-0.00289	-0.52148	
65	2.18791	-0.00477	-0.68256		65	2.08528	-0.00542	-0.73250	
66	2.14709	-0.00332	-0.66355		66	2.27748	-0.00764	-0.76545	
67	2.14752	-0.00306	-0.60372		67	2.10533	-0.00470	-0.67774	
68	2.23017	-0.00308	-0.89975	K6	68	2.45949	-0.00937	-0.95111	M4
69	2.28639	-0.00615	-0.62161		69	1.98595	-0.0034	-0.75675	
70	2.10017	-0.00228	-0.67693	K5	70	2.19897	-0.00257	-0.5847	M1,M4,M5,M6

Table 6. Regression analyses for KDS and Mex Mix families, Manhattan, 1974.

KDS, Manhattan, 1974					Mex-Mix, Manhattan, 1974				
Family	a	b	r	Synthetic	Family	a	b	r	Synthetic
71	2.33038	-0.00596	-0.89149		71	2.12635	-0.00298	-0.62060	M4, M5
72	2.10785	-0.00361	-0.62824		72	2.24953	-0.00706	-0.82013	M2
73	2.20506	-0.00387	-0.79191		73	2.1648	-0.00361	-0.58536	M4, M6
74	2.17508	-0.00290	-0.65480	K1	74	1.89750	-0.00214	-0.47882	
75	2.15083	-0.00284	-0.77876		75	2.05467	-0.00415	-0.52813	
76	2.09133	-0.00294	-0.45374		76	2.36277	-0.00590	-0.94311	M1, M5
77	2.15481	-0.00299	-0.90614	K5	77	1.9949	-0.00290	-0.37396	
78	2.31903	-0.00559	-0.74983		78	2.43659	-0.01122	-0.92927	
79	2.17268	-0.00302	-0.83680		79	2.29218	-0.00682	-0.78616	
80	2.09156	-0.00220	-0.51412	K5	80	2.11297	-0.00699	-0.36303	
81	2.17229	-0.00360	-0.70623		81	2.2340	-0.00565	-0.99291	
82	2.10416	-0.00205	-0.58914		82	2.1664	-0.00600	-0.89045	M2
83	2.28865	-0.00560	-0.91328		83	2.14137	-0.00452	-0.41481	
84	2.06297	-0.00193	-0.28067	K2	84	2.15585	-0.00545	-0.88853	
85	2.20701	-0.00486	-0.65579		85	2.19453	-0.00587	-0.86087	
86	2.15518	-0.00307	-0.78730		86	2.02394	-0.00150	-0.32669	M2, M6
87	2.25817	-0.0057	-0.88865		87	2.01800	-0.00247	-0.52005	
88	2.30814	-0.00679	-0.71835		88	2.0555	-0.00350	-0.53965	
89	1.80701	0.00228	0.34495	K2	89	1.83372	0.00046	0.07159	
90	2.24311	-0.00516	-0.52978		90	1.96408	-0.00275	-0.39921	
91	2.37710	-0.00707	-0.98824		91	2.07792	-0.00233	-0.44948	M1, M5, M6
92	2.18131	-0.00358	-0.74035	K4, K5	92	2.0525	-0.00426	-0.74383	
93	2.40395	-0.00771	-0.93302		93	2.20453	-0.00401	-0.67493	M6

Table 6. Regression analyses for KDS and Mex Mix families , Manhattan, 1974.

KDS, Manhattan, 1974					Mex-Mix, Manhattan, 1974				
Family	a	b	r	Synthetic	Family	a	b	r	Synthetic
94	2.08780	-0.00347	-0.63820		94	1.93212	-0.00022	-0.08716	
95	2.32628	-0.00721	-0.74329		95	2.14417	-0.00434	-0.55917	
96	1.99223	0.000535	0.11961	K6	96	2.19273	-0.00625	-0.90081	
97	2.42194	-0.00918	-0.97741		97	2.17337	-0.00483	-0.76957	
98	2.29619	-0.00478	-0.93304	K1,K5	98	2.08337	-0.00427	-0.72382	
99	2.20779	-0.00500	-0.66503		99	2.43422	-0.00993	-0.91444	
100	2.40177	-0.00784	-0.85452	K5	100	2.17426	-0.00331	-0.77972	M4

Table 7. Log W values (grams) for KDS and Mex Mix (parental families), Manhattan, 1974.

Synthetics (parental families)	Plant Density			Synthetics (parental families)	Plant Density		
	30,000	55,000	80,000		30,000	55,000	80,000
K-0	2.08	1.98	1.87	M-0	2.01	1.85	1.75
K-1	2.09	2.07	1.87	M-1	2.06	1.99	1.833
K-2	2.08	2.01	1.90	M-2	1.99	1.85	1.71
K-4	2.10	2.05	1.91	M-4	2.08	1.95	1.86
K-5	2.09	2.02	1.86	M-5	2.07	1.99	1.86
K-6	2.09	1.99	1.99	M-6	2.02	1.91	1.93

Table 8. Log W Values (grams) for KDS and Mex Mix, Manhattan, 1975.

Synthetic (KDS)	Density 30,000	42,500	55,000	67,500	80,000	Synthetic (Mex Mix)	Density 30,000	42,500	55,000	67,500	80,000
K-0	2.27	2.18	2.06	1.94	1.90	M-0	2.15	1.99	1.90	1.81	1.76
K-1	2.28	2.18	2.09	1.99	1.86	M-1	2.20	2.17	1.97	1.93	1.87
K-4	2.29	2.20	2.07	2.04	1.92	M-4	2.29	2.11	1.97	1.95	1.70
K-5	2.25	2.17	2.00	1.96	1.88	M-5	2.20	2.12	2.00	1.94	1.77
K-6	2.32	2.22	2.04	2.01	1.91	M-6	2.21	2.08	1.95	1.87	1.75

Table 9. Log W Values (grams) for KDS and Mex Mix, St. John, 1975.

Synthetic (KDS)	Density 30,000	42,500	55,000	67,500	80,000	Synthetic (Mex Mix)	Density 30,000	42,500	55,000	67,500	80,000
K-0	2.22	2.13	1.99	1.93	1.82	M-0	1.96	1.84	1.65	1.61	1.48
K-2	2.19	2.10	1.92	1.85	1.75	M-2	1.96	1.90	1.64	1.65	1.41
K-4	2.26	2.10	1.99	1.95	1.74	M-4	2.01	1.95	1.85	1.69	1.51
K-5	2.20	2.13	1.95	1.93	1.83	M-5	2.01	1.99	1.79	1.73	1.60
K-6	2.27	2.15	2.00	1.90	1.88	M-6	1.98	1.99	1.80	1.70	1.55

Table 10. KDS and Mex Mix Yields (KG) per ha. by Population for Manhattan, 1974.

Synthetics (parental families)	Plant Density			Synthetics (parental families)	Plant Density		
	30,000	55,000	80,000		30,000	55,000	80,000
K-0	3712	5465	6115	M-0	3188	4078	4854
K-1	3744	6603	6173	M-1	3557	5468	5821
K-2	3716	5758	6520	M-2	3051	3990	4495
K-4	3890	6328	6622	M-4	3651	5038	6090
K-5	3756	5870	6129	M-5	3653	5442	6068
K-6	3778	5480	7541	M-6	3300	4528	6964

Table 11. KDS and Mex Mix Yields (kg) per ha. by Density, Manhattan, 1975.

Synthetic	Density					Synthetic	Density				
(KDS)	30,000	42,500	55,000	67,500	80,000	(Mex Mix)	30,000	42,500	55,000	67,500	80,000
K-0	5580	6494	6377	6095	6557	M-0	4241	4342	4338	4500	4668
K-1	5794	6470	6761	6612	5820	M-1	4828	6258	5171	5796	6033
K-4	5980	6922	6526	7543	6685	M-4	5835	5529	5249	6073	4036
K-5	5371	6335	5578	6250	6098	M-5	4786	5588	5433	5855	4772
K-6	6312	7183	6047	6948	6564	M-6	4921	5126	4956	4967	4537

Table 12. KDS and Mex Mix Yields (kg) per ha. by Density, St. John, 1975.

Synthetic	Density					Synthetic	Density				
(KDS)	30,000	42,500	55,000	67,500	80,000	(Mex Mix)	30,000	42,500	55,000	67,500	80,000
K-0	5030	5736	5386	5868	5374	M-0	2782	3089	2484	2813	2467
K-2	4753	5516	4559	4952	4583	M-2	2856	3372	2405	3143	2145
K-4	5535	5335	5346	6050	5276	M-4	3184	3816	3878	3307	2668
K-5	4833	5806	4967	5811	5404	M-5	3217	4226	3422	3659	3260
K-6	5676	5987	5494	5204	6123	M-6	3042	4203	3482	3515	3005

Table 13. Analysis of Variance for Grain Yield, Log/Yield Plant from Density and Synthetics Study (parental families), Manhattan, 1974.

		MEAN SQUARES			
		Kansas Drought Synthetics (KDS)		Mex Mix (MM)	
Source	df	Yield/ha	Log Yield/Plant	Yield/ha	Log Yield/Plant
Replicate	1	7,413,093*	0.255**	80,938,704**	0.609**
Densities	2	295,259,904**	1.253**	192,959,984**	1,617**
Synthetics	5	6,537,364**	0.049**	31,974,272**	0.321**
Density x Syn.	10	4,531,372**	0.033**	6,179,649**	0.041**
Error	881	1,405,357	0.012	1,513,849	0.018

** Statistically significant at 1% level.
* Statistically significant at 5% level.

Table 14. Analysis of Variance for Grain Yield, Log Yield/Plant from Density and Synthetics Study, Manhattan 1975.

		MEAN SQUARES			
		Kansas Drought Synthetics (KDS)		Mex Mix (MM)	
Source	df	Yield/ha.	Log Yield/Plant	Yield/ha.	Log Yield/Plant
Replicates	3	2,847,042	0.013	1,449,620*	0.012*
Densities	4	2,636,926	0.485**	1,534,605*	0.582**
Error (A)	12	1,074,838	0.005	397,355	0.003
Synthetics	4	2,062,852*	0.011*	4,330,164**	0.033**
Density x Syn.	16	427,552	0.002	921,088	0.007
Error (B)	60	822,083	0.004	515,054	0.004

** Statistically significant at 1% level.
* Statistically significant at 5% level.

Table 15. Analysis of Variance for Grain Yield, Log Yield/Plant from Density and Synthetics Study, St. John 1975.

		MEAN SQUARES			
		Kansas Drought Synthetics (KDS)		Mex Mix (MM)	
Source	df	Yield/ha.	Log Yield/Plant	Yield/ha.	Log Yield/Plant
Replicates	3	1,771,599	0.014	2,822,879	0.052
Densities	4	1,129,304	0.574**	2,888,039	0.742**
Error (A)	12	821,087	0.006	889,823	0.019
Synthetics	4	1,921,799*	0.014	306,610**	0.059**
Density x Syn.	16	429,333	0.005	254,793	0.006
Error (B)	60	659,737	0.006	504,970	0.010

** Statistically significant at 1% level.
* Statistically significant at 5% level.

PREDICTING OPTIMUM PLANTING DENSITIES
FOR CORN (*ZEA MAYS* L.) SYNTHETICS

by

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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

1976

Planting improved corn hybrids and synthetic varieties at optimum densities is of particular importance for obtaining the higher grain yields of corn (Zea mays l.). Linear relationship between the logarithum of grain yield per plant and plant density has successfully been used in predicting optimum plant density for a specific corn hybrid and for a specific environment.

The objectives of this study were (1) to characterize the density response of individual families in two genetically diverse corn populations; (2) to determine if this logarithmic relationship between plant yield and density could be used to select families responsive to high density; (3) to determine if the linear logarithmic relationship adequately describes the density response of synthetics made up from selected families.

Individual families of KDS and Mex Mix corn populations were evaluated for density response by planting at 30, 55 and 80 thousand plants/ha at Ashland Agronomy Farm, Manhattan, in 1974. Ten selected families responsive to high plant density in each of the KDS and Mex Mix populations were recombined into high density KDS and Mex Mix synthetics. High density synthetics and other selected synthetics were compared with original populations at plant densities of 30.0, 42.5, 55.0, 67.5 and 80.0 thousand plants/ha at Manhattan and St. John,

1975. A logarithmic transformation (base 10) of grain yield per plant (W) for Manhattan 1974, Manhattan 1975 and St. John 1975 was made. Combined regression analyses of the 10 selected families for each of high density synthetics in 1974 showed a clear theoretical high density response over the original populations. But the regression analyses of these synthetics tested at Manhattan and St. John in 1975 indicated that high density KDS and Mex Mix synthetics did not show higher density response over the original population. However, the logarithm of grain yield per plant and plant density were negatively and highly significantly correlated in all tests.

Predicted optimum planting densities for Manhattan 1974 were very high and unrealistic and did not agree with calculated optimum densities of these synthetics tested at Manhattan and St. John 1975.

Possible reasons for differences between the two years predicted optimum planting densities may have been variation in plot size harvested and the methods of harvesting.