THE EFFECT OF ROW WIDTH AND PLANT POPULATION ON GRAIN YIELD, YIELD COMPONENTS, AND OTHER CHARACTERISTICS OF THREE CORN (*Zea mays* L.) HYBRIDS

by

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INTRODUCTION

Corn (*Zea mays* L.), a popular grain and forage crop, was traditionally grown in rows 91 to 112 cm (36 to 44 inches) apart because of the design of planting, cultivating, and harvesting machinery. In the past, the wide row spacing was necessary to facilitate horse-drawn tools. Development of suitable mechanized equipment for narrower rows and the availability of improved herbicides have generated interest in narrow-row spacings over conventional spacings.

Corn yield is a function of climate, soil, genotype, population, spacing, and available nutrients. Correlating these factors to produce the highest possible yields with greatest efficiency has been the aim of research workers and farmers everywhere since corn production began. The dynamics that influence the interactions of these functions are difficult to control and this limits the findings of research to a specific range of conditions.

Many of the population and row spacing investigations have been inconclusive; great variation was encountered from year to year and from location to location depending upon environmental and climatic conditions.

Establishing the proper plant population is one of the factors essential for obtaining maximum corn yields. The distribution of plants over the soil area has been suggested as a means for influencing yield as evidenced from equidistant spacing in corn. The yield of some hybrids is increased when planted thick and other hybrids are intolerant to dense stands.

Yield may very from season to season at any one location or hybrids may rank differently in the same season when grown at several locations because each hybrid has its own exclusive complex of genetic factors and physiological relationships that interact with environmental conditions prevailing at a specific location during a given season. Cultural practices chosen for a test such as date, rate of planting, fertilization, and row width, etc., can favor one hybrid over another; similarly, the weather pattern, rainfall quantity and distribution, frost and/or high temperatures may hinder one maturity group and favor another.

An experiment was initiated to determine the effects of row spacings, plant populations and their interactions on grain yield. Treatments imposed consisted of three high yield potential corn hybrids to evaluate possible differential response and interactions to varying plant population and row spacing.

REVIEW OF LITERATURE

Experimental Study of Plant Populations and Hybrids

Plant population per acre has long been recognized as one of the important factors in determining yield and the ultimate extent of return. As the number of plants increases, competition for materials in the soil becomes greater. Addition of fertilizers and irrigation water can alleviate the struggle for plant food to a certain degree, and thus enable a large number of plants to develop to the same size as a small number did before fertilizer was added.

Lang, Pendleton, and Dungan (1956) showed that highly productive soil increased grain yield per plant compared with the same number of plants on soil medium too low in productivity. Furthermore, this comparative increase in grain production per plant mounted as plants per acre increased. For instance, at 10,000 plants/ha (4000 plants per acre), the average yield of 9 single-cross hybrids was 2870 kilograms per hectare (45.7 bushels per acre) on the low-productive and 3422 kilograms per hectare (54.5 bushels) on the highly productive soil, an increase of 19 percent.

When the population was 20,000 plants/ha (8000 plants per acre), the increase in yield of the high over the low-productive soil was 27 percent. At 30,000 plants/ha (12,000 plants per acre), the increase was 43 percent; at 40,000 (16,000) it was 84 percent; at 50,000 plants/ha (20,000) it was 129 percent; and at 60,000 plants/ha it dropped a little but it was still high, being 118 percent (Lang *et al.*, 1956). Lang *et al.* concluded by saying that an increase in the productivity of the soil at any population rate increased the grain produced per plant and this tended to be accelerated as plants per hectare increased up to 50,000, beyond which, on the highly productive soil, it declined slightly.

This achievement of increased grain production at high fertility levels, according to these workers, is due to three adjustments:

(1) The plants may produce two or more ears per plant,

(2) The number of ears per plant may not increase, but the size of the ears may increase, and

(3) The percentage of stalk barrenness may be reduced.

Which of these responses predominates is influenced by the inherent characteristics of the hybrid or variety. Usually all three adjustments occur to some degree depending upon the circumstances.

Norden (1966) in Gainesville, Florida, grew two corn hybrids on fine Leon sandy soil at 5 plant populations and 4 bed heights in contrasting wet and dry years. A positive curvilinear relationship was observed between plant population and grain yield per hectare. On a per plant basis, increasing the population from 12,500 to 62,500 plants/ha (5,000 to 25,000 plants per acre) decreased grain yield 73 percent. Bedding increased grain yields in the wet year but not in the dry year. The grain yield response was more closely associated with the dry weight of roots than with the width or depth of the root clump. Plant height was not greatly affected by plant population or bedding and was not closely associated with root development.

Increased lodging at the higher plant populations appeared to be largely the result of a reduction in root density without an accompanying reduction in plant height. The dry weight of roots per plant was

29 percent greater in a dry than in a wet year; however, the grain yield was 40 percent less. Norden also reported an interaction between genotype, year and bedding in grain yield and plant height.

Andrew et al. (1963) studied six hybrids at four plant densities with three fertility levels over a four-year period in Wisconsin. They concluded that short season hybrids performed relatively better at the low fertility level while those of longer season benefitted more from increasing fertility except in dry years. On the average, the early maturing hybrids profitted more with increasing population, especially in the high rainfall-cool season of 1960.

Termunde, Shank, and Dirks (1963) studied eight hybrids at seven plant densities (10,000 to 80,000 plants per hectare) over a three-year period at four locations in South Dakota. The general approach was to compare adapted hybrids with later hybrids at each location and only a partial range of maturity was tested at a given location. Four of nine possible hybrid-x-rate interactions were significant. Termunde et al. concluded that adequate population levels may offset grain yield disadvantages which exist at lower rates when comparing an adapted hybrid with later corn.

One of the first investigators of maturity-x-rate interactions for yield in corn was Mooers (1920) who reported on planting rates and spacing for corn in Tennessee. He stated "different varieties require appreciably different rates of planting. In general, the small and short season varieties require thicker planting than the large, long season varieties."

Another early and longtime investigator of plant density effect on yield was Miles (1951) in Indiana. He compared three very early corns with a full season corn at four plant densities (17,500 to 42,500 plants per hectare) over a nine-year period. The very early corns made their top yields at 35,000 to 42,500 plants per hectare while the full season corn made its top yields at 27- 35 thousand plants per hectare. Miles recommended 20 percent greater planting rates for early corns over adapted corns.

Rounds et al., (1951) studied rate, method, and date of planting corn in Michigan. The 1947-48 results involving 31 commercially available hybrids tested at 17,500 to 42,500 plants per hectare showed a slight tendency for the earlier hybrids to give a higher response to rate of planting both years. The negative correlation between grain moisture and yield at high population was significant one year but not the other.

Duncan (1954) conducted experiments with three hybrids, designated as early, adapted, and late, at five plant densities (20,000 to 60,000) with two fertility levels on four soil types in Minnesota and Iowa. The late hybrid on high fertility level generally produced higher yields than adapted and early hybrids up to 40,000 plants per hectare. Above 40,000 the adapted hybrid was generally equal or higher in yield. In some cases early hybrid yielded more at 50,000 than the late hybrid at 40,000.

In Iowa where a tall, rugged, full-season hybrid was compared to a short, earlier hybrid in 16 experiments over a three-year period, there was not a significant hybrid-x-row spacing interaction. Thompson (1967), who conducted the experiment, stated that hybrids of the same maturity must be compared. When there is a difference in time of pollination, a differential response between hybrids may be caused by weather during the critical period rather than by row spacing.

It is commonly believed that higher plant populations can or should be used when grown in narrow rows. Yet, it is rare when a statistically significant population-x-row-spacing interaction appears. According to Thompson (1967), in 16 experiments at Iowa there was no significant population-x-row spacing interaction, although a hybrid-x-population interaction was common. It is true, however, that the response to narrow rows is greater at the moderate to high populations than it is at low plant populations.

The number of ears per stalk is determined by heredity and environment. Prolific strains produce multiple ears even under relatively unfavorable growing conditions. Single-eared hybrids vary widely in their tendency to produce more than one ear under high fertility and low population levels. Lang et al. (1956), in tests at Illinois, reported that of any of the 9 hybrids in the tests the two single-cross hybrids, Hy 2 x OH 7 and Wf 9 x OH 41, showed the greatest tendency to be multiple-eared at 10,000 plants per hectare and had the lowest percentage of barren stalks at 60,000 plants per hectare. Single-cross, WF 9 x C 103, on the other hand, exhibited the least number of second ears at low population levels and the greatest number of barren stalks at higher populations.

Lang et al. (1956) also found that stalk barrenness was affected more by population than by hybrid or fertility level. Dungan et al. (1938), in tests conducted in northern Illinois, found 1.2 percent with

30,000 plants, 15.7 percent with 40,000 plants, and 23.6 percent with 50,000 plants per hectare. The average number of ears per stalk was 1.01, 0.91, 0.83, and 0.81, for the various populations, respectively.

Increasing the population density delays plant development. Seed producers have noted this phenomenon and have suspected that silking is delayed more than is tasseling. A study was made of the dates of half-tassel and the half-silk stage of 9 hybrids in rate of planting tests in central Illinois. The increase in time between silking and tasseling due to thick planting was not great. It amounted to only a little over one day when the population was increased from 20,000 to 50,000 plants per hectare (Lang et al. 1956). The same workers also showed that the spread between tasseling and silking varied widely between hybrids and also between seasons. The interval was found to be much greater at populations above 50,000 plants than it was at or below this figure. The time between tasseling and the full-silk stage was much greater than that between tasseling and the half-silk stage. Retardation of silk emergence may be looked upon as an operation of plant adjustment to high population which in extremely thick stands would bring about complete barrenness.

Length of season requirement is a factor affecting the optimum rate of planting for maximum yields. Most investigators agree that early-maturing varieties can be planted thicker than late-maturing corn. Richey (1933) stated that the rank-growing, long-season varieties of the southern states will not tolerate nearly as thick planting as the smaller varieties of the north. Rossman (1955) in Michigan found that there was a slight tendency for the earlier hybrids to make a greater response than the later hybrids to rate of planting.

Hybrids differ with respect to their response to population levels. Lang (1956) reported that the single-cross hybrid, Hy 2 x OH 7, proved highly tolerant to high rates of planting and made its highest yield at 50,000 plants per hectare. Single-cross, WF 9 x C 103, on the other hand, was less tolerant and made its highest average yield at 30,000 plants per hectare. Stepping the population up to 60,000 plants per hectare reduced the yield of the less tolerant hybrid 32 percent. In general, hybrids which showed a tendency to be multiple-eared at low population rates responded the best to high rates of planting.

Lang (1956) stated that the effect of reduced quantities of sunlight on the growth and development of corn plants in many ways parallels that which is found at high population rates. This points, then, to lack of solar energy as a factor which inhibits the photosynthetic processes so necessary for full expression of plant capabilities.

However, in some cases some plants seem to be hindered less than others by shading. Soil organic matter too could be another factor which operates to set the level of yield under high populations.

Weight of ear decreased with increased population in all experiments, except in the case of hybrids or varieties which tend to produce more than one ear at low population levels. Perhaps, a more nearly correct way to express this rule would be to say that weight of grain per plant decreased with increased population.

Hunter and Yungen (1955) of Oregon found that maximum yields obtained were associated with ear weights of 0.24 to 0.26 kg (0.52 to 0.57 lb.). However, they concluded that ear weight per plant cannot be applied in the same way at all locations as an index to optimum rate of planting.

The response of corn hybrids to soil water and nitrogen treatments has been reported by several researchers (Denmead and Shaw, 1960; Howe and Rhoades, 1955; Robins and Domingo, 1953).

Bruce, Sanford, and Myhre (1966) studied grain yield and several yield components of a cytoplasmic, male-sterile, single cross, corn hybrid and its fertile counterpart. They measured imposed soil water tension regimes to applied nitrogen levels. The male-sterile strain consistently yielded more grain than its fertile counterpart, primarily because of the greater number of second ears produced.

At the 6-bar maximum soil water tension imposed during fruiting, the ear length and diameter of male-sterile corn were significantly greater than those of the male-fertile; however, at the 0.3 bar maximum soil water tension imposed during fruiting, ear dimensions of the two strains were similar. Although the sterile strain consistently produced a greater number of ears under all conditions of these experiments, reduced levels of nitrogen and soil water more seriously affected ear diameter and length of the fertile strain.

In their attempts to maximize corn yields by increasing rates, many growers have commented that the prevalence of smut (Ustilago maydis (D.C.) (cda.) is greater in dense stands than in fields planted at lower rates.

Rutger and Risius (1966) from their studies reported average smut infection of a group of 30 corn hybrids at 5 locations increased as plant populations were increased from 52,000 to 72,500 plants per hectare

(20,800 to 29,200 plants per acre). A highly significant hybrid-x-population interaction for incidence of smut indicated, according to these workers, that hybrids respond differently to planting rates.

Although most of the hybrids were believed to be relatively tolerant to smut, highly significant hybrid differences in infection were observed. Smut infection, averaged over locations and populations, ranged from a low of 2.9 percent for hybrid 16 to a high of 18.3 percent for hybrid 26.

Corn tillers are familiar to everyone associated with growing of this crop. Factors which favor the production of tillers as listed by Williams and Etheridge (1912) are:

(1) highly productive soil with adequate moisture supply,

(2) a strain of corn having a highly tillering habit,

(3) thin spacing of plants, and

(4) a time of planting which is favorable for vigorous growth.

Tillering is the response of the plant to environmental conditions which can support a larger population than is present. Tillers are, therefore, more numerous at low than at high population levels on highly productive soil.

Many investigators have found that removal of tillers is of no practical advantage. Thompson, Mills, and Wessels (1930) found that removal of tillers from sweet corn tended to reduce the yield of marketable ears, especially in the case of tiller removal after the plants had begun to tassel.

Lyon (1905) and Dungan, Lang, and Pendleton (1958) stated that the time of planting plays a minor role in determining the optimum planting rate. In general, with crops such as corn which tiller relatively little, thin planting tends to slightly hasten plant development. Medium-late planting of corn has been observed to result in plants of greater height. Early planting of seed of the same hybrid results in plants of lesser height.

Andrew (1967) grew early single-eared and late multiple-eared sweet corn hybrids in a range of spacings, populations, and row widths over a 5-year period at the Arlington Experimental Farm, Wisconsin. Determinations were made of snapped weight in the husk, usable ear weight, number of usable ears, percentage of usable ears, maturity, barrenness and multiple earing on a usable and total ear basis, concern being primarily with the last three measurements.

Prolific Hybrid 2 was more responsive to season in production of weight of snapped corn in the husk. Hybrid 1 was more dependent upon plant population for production of number of usable ears while hybrid 2 was more able to compensate at low populations by producing more ears per plant. Percentage of usable ears was markedly higher for both hybrids at all treatments in the drier year, indicating rainfall had its greatest effect on activation of buds rather than on proportion of buds completing development. While barrenness was directly proportional to population, the single eared hybrid showed relatively more barrenness at the high population and under dry conditions. Population was of greater importance than row width in terms of response elicited for the measurements of these studies.

Pendleton et al. (1968) conducted field investigations at Urbana, Illinois, concerning the relationship of leaf angle and canopy shape of grain yield and apparent photosynthesis of two hybrids. A backcrossderived isogenic single-cross hybrid ('C 103' x 'Hy') carrying the l_{g2} gene for erect leaf and its counterpart with normal (horizontal) type leaf and "Pioneer 3306" were used. Comparing the two isogenic hybrids for leaf angle, an advantage of 2,507 kg/ha (41 percent) was found for the erect leaf type. This was accomplished with similar LAI of 4.0. The normal leaf version of this particular single cross (C 103 xHy) has never been noted for tolerance to high plant population.

When grown under artificial shade, in other experiments, this hybrid yielded 40 percent less grain than when grown in the sun. The results for the isogenic hybrids indicate that lack of light penetration into a canopy of corn may be one important factor causing intolerance of certain varieties to high planting rates.

Mechanical manipulation of the leaves of a widely grown commercial hybrid, "Pioneer 3306, into a more upright position resulted in grain yield above that produced by the same hybrid in its normal leaf orientation and canopy shape. Apparent photosynthesis measurements on individual corn leaves showed the relative efficiency of CO_2 fixation/unit of incoming sunlight to steadily increase as the leaf angle decreased.

An early and a late maturing hybrid corn grown at different plant populations and row spacings were compared for proportion of ears, stalks, and husks to whole plant by Bryant and Balser (1968). Populations of 39,500, 49,400, 66,700, and 98,800 plants/ha within row spacings of 36, 53, 71, and 89 cm were studied. The corn was harvested when the grain was well dented and silage and grain yields were also obtained.

The stalks, leaves, and husks as determined by hand separations, comprised a larger proportion, and the ears a smaller proportion of the total dry weight of the late than early hybrid. Each year the proportion of stalks to total dry weight of both hybrids was the smallest from rows 53 cm apart. The weight of the total corn plant, averaged for both hybrids at all population levels decreased slightly with each increase in distance between rows.

As plant population increased, the weight of the individual plant constituents, averaged for both hybrids, at all row spacings, decreased proportionally. The average yield of silage was larger but the average yield of grain was smaller from the late than the early hybrid. Planting at 89,800 compared with 39,500 plants/ha gave larger silage yields with either hybrid.

Rütger and Crowder (1967) evaluated the effect of population and row width on corn silage yields. Three corn hybrids were evaluated at two locations for 3 years at 50, 88, and 125 thousand plants per hectare in 92-cm row widths. Two additional row widths, 46 cm and a double row (Paired rows 15 cm apart, with 92 cm from the middle of one pair to the middle of the next pair) were employed at the 88,000 planting rate.

Maturity was delayed at increasing populations. The amount of dry shelled grain (DSG) in the silage decreased at the higher populations. Total dry matter (TDM) increased about 6 percent as the population was raised from 50,000 to 88,000 plants. TDM yield at 125,000 plants was the same as at 88,000 plants per hectare. Changing the row width within the 88,000 planting rate had no appreciable effect on silage characters measured. There was no indication of a hybrid-x-population (or row width) interaction for any of the characters.

Mooers (1910) presented the general proposition that the taller the variety, the less will be the number of stalks per acre which will produce the greatest yield of grain.

With the advent of short hybrids, corn growers saw the possibility of increasing the population of corn plants per acre and thereby augmenting grain yields over the full-length hybrids.

Duncan (1952) observed incomplete filling of cobs on dwarf hybrids in heavy stands. He further stated that it is not known whether this is caused by heavy compact foliage interfering with pollen-silk contact or due to some internal cause.

Timmons, Holt, and Morghan (1966) conducted experiments to study the effect of corn stand on yield, evapotranspiration, and water-use efficiency at different stages of plant growth. Five corn populations, within the limits of 15,000 to 60,000 plants per hectare were planted in a Latin square design at 7 and 10 locations during 1963 and 1964, respectively. Under adequate moisture conditions in 1963, yields ranged from 3768 to 8415 kg/ha (60 to 135 bushels per acre) at optimum stands of 35,000 to 55,000 plants/ha (14,000 to 22,000 plants per acre), whereas, yields of 62.8 to 4710 kg/ha (1 to 75 bushels) at stands of 15,000 to 30,000 plants per hectare were produced under the limited moisture conditions in 1964. Evapotranspiration from planting to maturity ranged from 34.3 to 52.3 cm (13.5 to 20.6 inches) and 23.9 to 43.4 cm (9.4 to 17.1 inches) for 1963 and 1964, respectively.

Except at 2 of the 17 locations, evapotranspiration was not affected significantly by stand at any growth stage during the 2-year period.

Water-use efficiency increased as corn yield increased and reached a maximum of 206 kilograms (454 pounds or 8.1 bushels) of corn per inch of evapotranspiration. No definite relation of water-use efficiency to stand was found for grain yields since optimum corn stands were related to growing seasons. Forage production and water-use efficiency generally increased with higher plant populations, so there was a close relationship between them during the 2-year period.

Yao and Shaw (1964b) did a study on net radiation as affected by plant population and planting pattern of corn. They reported that maximum soil evaporation estimated from net radiation data indicated that the 53.3 cm (21-inch) single planting could evaporate up to 7.6 cm (3 inches) of water; the 53.3 cm (21-inch) double planting, 5.1 cm (2 inches) of water; the 106.7 cm (42-inch) single planting, 10.7 cm (4.2 inches) of water; and the 106.7 cm (42-inch) double planting, 7.1 cm (2.8 inches) of water for the period July 2 to September 30.

Alessi and Power (1965) studied the effects of total available soil moisture, plant population, and N fertilization upon dryland corn production at 2 locations, over a 6-year period in Mandan, North Dakota.

Forage and grain yields were highly correlated with total available moisture (soil moisture at planting plus precipitation). The correlation coefficient indicated that about 86 percent of the total variation in forage and 71 percent of the total variation in grain yield were accounted for by variations in total available moisture. The regression equations indicated that a yield response of about 0.73 ton of silage and 121.3 kilograms (267 pounds or 4.8 bushels) of grain per acre could be expected for each additional inch of available moisture.

At least 15.2 cm (6 inches) of available water was required before any grain yield could be expected. Total available water was a better measure for predicting corn yields than available water at planting or seasonal precipitation alone. Optimum population at each location was 25,000 plants per hectare. Applications of N were of little benefit.

In reporting the yield of corn from various types of experiments where leaf area is taken, calculation of grain per square decimeter of leaf area, relative maximum yield, and percent actual yield of the relative maximum yield was suggested for evaluating the effects of treatments on yield by Earley (1965). From his experiment he reported that the top third leaves of the corn plants produced more grain per unit of leaf area (3.7 g/dm^2) than any other group of leaves from the plant. The bottom third leaves yielded 74 percent of its relative maximum yield. Presumably, the bottom leaves received more mutual shade than the middle leaves.

Interrelationships among yield components of corn indicated that plant yields were inversely associated with the number of stalks per unit area. Plot yields were directly associated with number of plants per unit area and inversely associated with ear weights. Highest yields were obtained from 50,000 to 175,000 plants per hectare, especially when planted in narrower rows.

Holt and Timmons (1968) evaluated corn grain yield response to different levels of soil, water, precipitation, and plant population during the rapid growth period of corn by multiple regression using 4 years field data.

For 17 locations showing a yield response to stand, multiple regression accounted for 91 percent of the variation in grain yields during the 4-year period. Estimated corn yields from the developed equation varied from 0 to 8976 kg/ha for all possible combinations of the independent factors.

The corn growth interval from 30-cm plant height to silking was divided into two equal time periods. Precipitation received during the second period (late July and early August) exerted a greater influence on corn yields than did that received during the first period (early July). With increased precipitation during the two periods, the optimum part of the stand-yield curve shifted to correspondingly higher stands.

Effect of stand on the performance of a prolific and a non-prolific double cross corn hybrid was conducted in Georgia by Crews and Fleming (1965).

Yields of 'Pfister 653', a predominantly 2-eared, white double cross hybrid and 'Tenn. 90', a 1-eared, yellow double cross were significantly lower at the 73 percent stand level than for the 100 percent check. The yields at this level were 85 and 86 percent of the full-stand checks. With a significant increase in ear size, plants of the 2-eared hybrid had a greater increase in yield than plants of the 1-eared hybrid as space per plant increased.

Colville _et al_. (1964) conducted ten irrigated corn experiments involving 6 hybrids covering a range of maturities planted at several populations during the period 1956 to 1959. The adapted full season hybrid A.E.S. 806 produced highest average yields at 40 to 50 thousand plants per hectare, but at greater populations, grain yields were slightly depressed. Portions of the yield losses associated with planting early as compared to full season hybrids could be recovered by planting at higher populations per hectare.

Colville et al. concluded that productivity level of the experimental areas and hybrid markedly influenced the slope, direction, and shape of grain yield curves. The researchers suggested that if maximum yield of each hybrid is to be realized it must be grown under populations and production practices that maximize its potentials. A limitation of any production factor as illustrated in their experiment, could well mean the discarding of an excellent hybrid without noting its full potential.

Row Spacing Experiments

Many experiments have been conducted during the past few decades on the effect of row spacing on the yield of row crops.

Traditionally, corn (*Zea mays* L.) has been grown in rows spaced from 91 to 112 cm (36 to 44 inches) apart to accommodate horse-drawn planting, cultivating, and harvesting machinery. Modern tractors and implement wheels do not limit row spacings so much, and the trend toward higher plant populations has aroused interest in narrower rows to give more uniform planting.

Experimental attempts to evaluate the effects of row spacing in corn have produced erratic results. Some have shown no differences of one spacing pattern over another (Bryan, Eckhardt, and Sprague, 1940; Stickler and Laude, 1960). Others have shown from a 5 percent yield advantage for narrow rows (Pendleton and Seif, 1961) to as much as

38 percent yield advantage (Colville and Burnside, 1963). Pfister (1942) noted a 1696 kg/ha (27-bushel per acre) yield advantage for 50-x-50 cm (20-x-20-inch) spacing over 102-x-102 cm (40-x-40-inch) spacing.

Yao and Shaw (1964a) found as the row width was decreased from 106 cm to 81 cm to 53 cm (42 inches to 32 inches to 21 inches), yield increased. Their experiment was conducted using two populations. One experiment had single plant hills and the other had two plants per hill. The highest average yield was recorded at the high population in 53 cm rows. They also found the 53 cm rows to produce more grain per acre-inch of water used than any other row spacing.

In Kansas, Stickler (1964) studied both irrigated and non-irrigated trials to measure performance of corn in 50-, 76-, and 102-cm (20-, 30-, and 40-inch) rows at varying plant populations. Under irrigation, highest yields were obtained with either 50,000 or 60,000 (20,000 or 24,000 plants per acre). Non-irrigated corn yielded best at 40,000 (16,000 plants per acre). Fifty cm (20-inch) rows exceeded 102-cm (40-inch) rows in yield by 6 percent under irrigation and by 5 percent in non-irrigated trials. This superiority was mainly associated with more ears per 100 plants (more 2-eared plants and fewer barren plants).

Grain protein percentage in non-irrigated trials in 1963 decreased with increased stand density (increased yield) in 102-cm (40-inch) rows, but tended to remain rather stable over different stand densities in 50-cm and 76-cm (20-inch and 30-inch) rows. In 1963, leaf-area portion (per-plant basis) was highly associated with grain yield per plant ($r = .895^{**}$), but was significantly influenced only by plant populations and not by row width.

Stickler (1964) suggested that yield advantages in narrow rows 50 to 76 cm (20 to 30 inches) probably resulted from more ears per 100 plants, more multiple-eared plants, and fewer barren plants rather than from more net photosynthesis and higher grain yield per ear-bearing plant.

The main effect of spacing on yield is believed largely due to a change in the radiant energy distribution. With closer and more uniform spacing of plants, it could be assumed that more radiant energy would be intercepted by the plants and that less would fall on the soil surface to cause evaporation. Higher plant populations could have a similar effect.

Tanner, Peterson, and Love (1960) measured the radiation exchange in a corn field and the energy available for evaporation. They found that the maximum evaporation loss could constitute from 25 to 50 percent of the total evapotranspiration, depending upon the population and the method of planting. Aubertin and Peters (1961) also measured net radiation interception and found that spatial distribution of the plants had a large effect on the amount of energy absorbed by the plants. Denmead, Fritschen, and Shaw (1962) reported on the spatial distribution of net radiation in a corn field where miniature net radiometers were used to measure the net radiation. Their results indicated that a row spacing of less than 102 cm (40 inches) might increase the energy available to the crop for photosynthesis by 15 to 20 percent.

In nearly all cases the components of yield (ears per plant and weight per ear) in 106 (42-inch) rows were adversely affected as the population increased over an equidistant spacing pattern (Hoff and

Mederski, 1960). As the population increased from 20,000 to 60,000 (8,000 to 24,000 plants per acre), the yield of both the 106 cm (42-inch) rows and equidistant pattern also increased; however, the yield of the equidistant spacing was consistently higher than the 106 (42-inch) row spacing. Ears per plant were lower for the 106-cm (42-inch) row spacing and as the population increased, the ears per plant decreased faster in the 106-cm (42-inch) row spacing than the equidistant spacing.

Ear weight from the equidistant spacing was about 51 grams (0.1 pound) less than that from the 106 cm (42-inch) rows and in both cases decreased linearly with increased population. Thus, the reduced yield was attributed to the reduced number of ears per plant. When looking at the spacing patterns of this experiment, there were 106 cm (42-inch) rows compared to 71-, 58-, 50-, 46-, and 41 cm (28-, 23-, 20-, 18-, and 16-inch) row spacings at five populations. As the row width decreased and the population increased, the yield was increased.

Pendleton and Seif (1961), using a <u>brachytic</u> <u>2</u> dwarf hybrid, found 76-cm (30-inch) rows to outyield both 50-cm and 102-cm (20-inch and 40-inch) rows by about 5 percent. Most of the variation in yield was attributed to ear weight. Maximum yield was attained at 76-cm (30-inch) row spacing at 40,000 to 50,000 (16,000 to 20,000 pts/acre) plant population. The dwarf corn performed similarly to normal corn. The narrow rows required an increased population for maximum yields.

Yao and Shaw (1964b), conducted experiments at Ames, Iowa, in 1960 and 1961 to measure radiation interception and water use by corn plants with different plant populations and planting patterns.

Net radiation was measured 1 m above the crop surface and 15 cm (6 inches) above the soil surface. Net radiation at 1 m above the crop surface was usually higher on 102-cm (42-inch) rows than 53-cm (21-inch) rows and was higher on single plantings than on double plantings. This was believed to be due to a difference in the albedo of a crop surface and a moist soil surface. The difference in net radiation at 1 m above the crop surface between treatments was high at the beginning of the season and gradually decreased as the season progressed.

Bryan et al. (1940) in Iowa reported the results of a four-year test of corn in which plants grown 4 per hill in 102-cm (42-inch) rows were compared with plants grown 1 per hill in rows 53-cm (21 inches) apart in both directions. The population was 35,500 plants/ha (14,224 plants per acre). The average yield of grain per hectare was 5049 kg/ha for the 53-cm (80.4 bushels for the 21-inch) spacing and 4854 kg (77.3 bushels) for the 106 (42-inch) spacing. The 106 (42-inch) spacing had a distinct advantage in lodging resistance. Collins and Shedd (1941) reported the results of comparison made over an eight-year period between plants grown 4 per hill at 106.7-x-106.7-cm (42- x 42-inch) spacing and plants grown 1 per hill at 53-x-53-cm (21-x-21-inch) spacing.

The average yield of 53- x 53-cm (21- x 21-inch) spacing was 4283 kg/ha (68.2 bushels per acre) and that of 106.7- x 106.7-cm (42- x 42-inch)spacing was 3755 kg/ha (59.8 bushels per acre), a difference of 528 kilograms (8.4 bushels). A comparison between plants grown 2 per hill at 76- x 76-cm (30- x 30-inch) spacing and plants grown 1 per hill at 76- x 38-cm (30- x 15-inch) showed only 12.9 kilograms (0.2 of a bushel) difference as a four-year average.

Pfister (1942) in Illinois compared the cost of growing corn in hills spaced 50 cm (20 inches) apart in 50-cm (20-inch) rows with checked corn in hills spaced 102 cm (40 inches) apart each way. He used a disk to prepare the seedbed for the corn in 102-cm (40-inch) rows and a field cultivator for the closely spaced corn. He used a cultivator for the 102-cm (40-inch) rows, but used a harrow and a weeder on the other corn. The cost per acre was $4.15 for conventional check-row corn and only $1.80 for the closely spaced corn. Yields, which represented an average of three-year's tests, were 4208 kilograms and 5884 kilograms per hectare (67.0 bushels and 93.7 bushels per acre), respectively, for these two methods.

Nunez and Kamprath (1969), in North Carolina, studied relationships between row width, N response, and plant population on growth and yield of corn. Their experiment consisted of three plant populations - 34,500; 51,570; and 69,000 plants per hectare (14,000; 21,000; and 28,000 plants per acre), three nitrogen rates - 112, 168, and 280 kg/ha (100, 150, and 250 lb/A), and two row widths - 53 and 106 cm (21 and 42 inches).

They reported that the yield of grain per hectare of the long season hybrid was not influenced by row width except under drought conditions where 53-cm wide rows gave higher yields than 106-cm wide rows. The leaf area index increased linearly as the plant population of corn was increased from 34,500 to 69,000 plants per hectare. The leaf area per plant, however, decreased as the plant population increased. Nitrogen rates had no effect on leaf area per plant nor leaf area index.

The yield of grain per plant was dependent upon the leaf area per plant. The efficiency of a given leaf area to produce grain was higher as nitrogen rates increased.

Jump (1967) reported data obtained involving population-row spacing studies from Purdue, Illinois, Pennsylvania and Delaware Universities. These experiments were combined over years and locations and subjected to a multiple regression analysis. The results indicated a non-significant correlation between row width and yield, a highly significant multiple correlation between row width, population and yield.

EXPERIMENTAL PROCEDURE

To evaluate the effects of row width and plant population and their interactions on corn yield three hybrids were tested at the Kansas State Agronomy Farm, Manhattan, and the Corn belt Experiment Field, Powhattan. The treatments consisted of combinations of three spacings, three plant populations and three hybrids.

The soil of the Manhattan farm was a moderately drained, dark colored, unnamed silt loam bottom land site. The soil at Powhattan was a Grundy silty clay loam. The fields were fall plowed and 223 kilograms (200 pounds per acre) of N, 91 kilograms (80 pounds per acre) of P_2O_5, and 22.8 kilograms (20 pounds per acre) of K_2O per hectare were applied and disked in on April 18 at Powhattan. At Manhattan 68 kilograms of nitrogen per hectare as 32-0-0 was applied on April 29, 1968. Annual rainfall received was 105.9 cm (41.7 inches) at Powhattan and 81.8 cm (32.2 inches) at Manhattan. Six month (April - September) precipitation was 59.1 and 83.7 cm at Powhattan and Manhattan, respectively.

The three hybrids used in the experiment were: US 523W - a full season white hybrid, Pfister SX29 - a single cross yellow hybrid, and Dekalb XL362 - a 3 way cross yellow hybrid, both medium maturing.

To eliminate yield variability related to poor germination of specific seed lots, plots were hand planted at twice the desired populations in row spacings of 50, 76, and 102 cm (20, 30, and 40 inches) and when the plants were about 30 cm (1 foot) tall were thinned to 40-, 50-, 60-thousand plants per hectare (16-, 20-, and 24 thousand plants per acre). Extra plants were left in adjacent hills to correct for missing hills. A split-plot design was used in the experiments with row-spacings as main plots and sub-plots of combinations of populations and hybrids, randomized within row spacings. Three replications were used per experiment. Planting was done May 11 at Powhattan and on May 18 at Manhattan.

The plants in the 50 cm rows were 49.8, 39.9, and 33.3 cm (19.6, 15.7, and 13.1 inches) apart, respectively for the 40,000, 50,000, and 60,000 plants per hectare. In the 76 cm rows the plants were 33.0, 26.6, and 22.4 cm (13.0, 10.5, and 8.8 inches) apart; and for the 102 cm rows the plants were 24.9, 19.8, and 16.5 cm (9.8, 7.8, and 6.5 inches) apart, respectively, for 40,000, 50,000, and 60,000 plants per hectare.

Excellent weed control was obtained at the Manhattan farm by 80 percent wettable atrazine applied at 2.95 kilograms per hectare (2.6 pounds per acre). A spray of 257 grams (1/4 pound per acre) 2,4-D amine per hectare did not control weeds well at Powhattan and roto-tilling and hand hoeing was required.

Plot length was 6.1 m (20 feet). Four 102-cm, four 76-cm, and eight 50-cm rows constituted sub-plots. At harvest, September 20, Powhattan, and September 27, Manhattan, yield data were taken from the center 2 rows of 76- and 102-cm plots, and from the center 4 rows of 50-cm plots. Stand and ear counts were made prior to harvest for ear number and ear weight determinations. Shelling percent was computed from ear weight and grain weight. During the shelling process no correction was made for moisture content of grain or cobs but yields are reported as kilograms per hectare of shelled grain adjusted to 15.5 percent moisture content.

Yield and other treatment comparisons were made by analysis of variance and L.S.D. (Least Significant Difference) techniques (Duncan, 1955).

RESULTS AND DISCUSSION

Stand Establishment

Stand count was made prior to harvest for determination of establishment of each hybrid. Analysis of variance for percent stand indicated that hybrids differed significantly[1] in establishment at Powhattan (Table 1) whereas at Manhattan there were no significant differences among hybrids nor other factors as observed from F values (Table 2).

Table 1. Analysis of variance for stand establishment at Powhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	307.55	
Row width	2	86.92	2.17
Error (A)	4	40.09	
Population	2	23.35	0.28
Hybrid	2	296.63	3.50*[1]
Row width x population	4	28.43	0.34
Row width x hybrid	4	89.50	1.06
Population x hybrid	4	87.49	1.03
Row width x population x hybrid	8	77.23	0.91
Error (B)	48	84.75	

[1]The terms highly significant (**) and significant (*) will be used to designate probabilities of less than 0.01 and between 0.05 and 0.01, respectively.

Yield

Grain from the various combinations of row width, plant population, and hybrid was harvested and analyses of variance were made on yield, components of yield, percent lodging, dropped ears, maturity (days to 50 percent silking), shelling percentage, and percent moisture content at harvest.

Table 2. Analysis of variance for stand establishment at Manhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	1.64	
Row width	2	78.12	1.56
Error (A)	4	50.00	
Population	2	83.04	2.20
Hybrid	2	35.84	0.95
Row width x population	4	20.50	0.54
Row width x hybrid	4	35.52	0.94
Population x hybrid	4	30.94	0.82
Row width x population x hybrid	8	68.76	1.82
Error (B)	48	37.68	

Highly significant differences were found for yield among the three hybrids at both locations (Tables 3 and 4). No significant differences were found among plant populations either at Powhattan or Manhattan. However, there was a significant interaction between row width and hybrid at Manhattan.

Table 3. Analysis of variance on yield at Manhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	168.60	
Row width	2	562.99	2.12
Error (A)	4	265.50	
Population	2	10.13	0.07
Hybrid	2	1738.24	11.37**
Row width x population	4	14.58	0.10
Row width x hybrid	4	400.28	2.62*
Population x hybrid	4	166.18	1.09
Row width x population x hybrid	8	133.75	0.74
Error (B)	48	152.93	

Table 4. Analysis of variance on yield at Powhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	107.90	
Row width	2	1163.50	5.20
Error (A)	4	223.66	
Population	2	175.72	2.46
Hybrid	2	2354.54	32.97**
Row width x population	4	58.70	0.82
Row width x hybrid	4	59.92	0.84
Population x hybrid	4	163.15	2.28
Row width x population x hybrid	8	90.62	1.27
Error (B)	48	71.42	

A significant row width x hybrid interaction on yield at Manhattan (Table 5) shows DeKalb XL362 yielded similarly and lowest in all three row widths. Pfister SX29 yielded higher than the other two hybrids and yielded similarly in the narrower rows as compared to the 102 cm rows. US 523W yielded much higher in 76 cm rows than in any of the other rows.

Table 5. Row width x hybrid interaction on yield at Manhattan, 1968.

	Hybrid		
Row width	US 523W	Pfister SX29	DeKalb XL362
50 cm	7366 ab[1]	7699 a	6770 a
76 cm	8365 a	7731 a	6694 a
102 cm	6870 b	7498 a	6701 a
Average	7536	7662	6720

[1]Values followed by a common letter were not significantly different at the 0.05 level of probability (Duncan, 1955).

The spacings and plant populations were pooled into a composite mean for the hybrids since they were significant for most of the factors considered in the experiment (Tables 6 and 7).

Table 6. Yield, maturity, shelling percent, and percent lodging of three hybrids at Manhattan, 1968.

Hybrid	Yield (kg/ha)	Maturity (days to 50% silking)	Shelling percent	Lodging percent
US 523W	8480 a[1]	72.7 a	81.2 b	9.8 a
Pfister SX29	8643 a	71.9 a	83.0 a	2.0 b
DeKalb XL362	6720 b	66.1 b	79.8 c	3.3 ab
Average	7297	70.4	81.4	5.0

Table 7. Yield, maturity, shelling percent, and percent lodging of three hybrids at Powhattan, 1968.

Hybrid	Yield (kg/ha)	Maturity (days to 50% silking)	Shelling percent	Lodging percent
US 523W	7172 b[1]	77.6 a	81.6 b	10.5 a
Pfister SX29	8239 a	75.6 b	85.9 a	5.9 b
DeKalb XL362	7085 b	71.0 c	84.2 ab	5.0 b
Average	7567	74.7	83.9	7.2

At Powhattan Pfister SX29 yielded significantly higher than the other two hybrids while at Manhattan Pfister SX29 and US 523W did not vary significantly in yield (Tables 6, 7, and Fig. 1). At both places DeKalb XL362 matured the earliest, silking being a little slower at Powhattan. Pfister SX29 had the highest shelling percentage at both

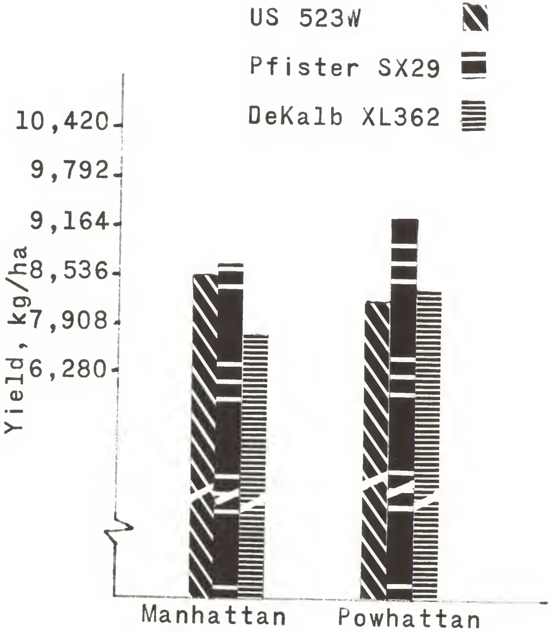

Fig. 1. Corn yield as affected by hybrids, two locations.

places and was significantly different from the other hybrids at Manhattan. At both locations US 523W lodged the most.

Comparing the two locations, yields were generally higher at Powhattan over all row widths and plant populations (Table 8). This could be attributed to the more favorable precipitation and temperature that existed at Powhattan.

Table 8. Average corn yields for different row width and different populations at two locations, 1968.

Row width	Manhattan	Powhattan kg/ha (15.5% moisture)	Average of two locations
50 cm	7279	7837	7561
76 cm	7593	7768	7680
102 cm	7021	7090	7058
Average	7297	7567	
Plants per hectare	**Manhattan**	**Powhattan**	**Average**
40,000	7329	7379	7354
50,000	7266	7636	7442
60,000	7310	7674	7492
Average	7297	7567	

Although statistically nonsignificant, yield tended to increase as row width was narrowed from 102 cm to 50 cm. This was particularly evident at Powhatten (Table 8). Averaged over hybrids and populations 50-cm rows at Powhattan had 0.8 and 9.5 percent or 69 and 735 kilograms per hectare yield advantage respectively over the 76 and 102 cm rows. Row widths of 102 cm at both locations resulted in considerably lower yield when compared to 50- and 76-cm rows.

At Manhattan narrowing row width from 102 cm to 76 cm increased yield, but as row spacing was narrowed further a yield decline of 314 kilogram per hectare was observed. Narrowing row spacing means exposing more leaf area over the ground surface. In drier areas or seasons evaporative loss is small because there is little moisture on the surface and uniform plant distribution over the area, instead of reducing evaporative loss, enhances water loss through transpiration which is the main pathway by which water is taken from the soil. And the more leaf area exposed to radiant energy from the sun, the greater the water loss.

The yield decline in 50-cm rows over the 76-cm row spacings at Manhattan may be best interpreted within the context of this reasoning. In other words greater light interception in the 50-cm rows failed to offset a greater transpiration rate.

Comparison of population effect on yield at both locations shows that there was yield superiority at Powhattan at all levels, being highest at the highest population, 60,000 plants per hectare. Since the narrowest row - 50-cm - averaged over populations and hybrids, and also the highest population - averaged over row width and hybrids - at Powhattan resulted in highest yield, this further proves the assertion that high plant populations and narrower rows respond where there is more favorable precipitation and adequate plant nutrients to offset competition.

At Manhattan, where moisture was below optimum in contrast to Powhattan, a completely reverse situation took place. The lowest population per hectare yielded slightly higher than the other two populations, but there was no appreciable yield difference among the three population levels at Manhattan (Table 8).

The combined effect of various row-spacings, hybrids, and plant populations is presented in Table 9 for Manhattan and Table 10 for Powhattan.

Table 9. Corn yields for different row spacings and different plant populations by hybrid, Manhattan, 1968.

Row width	Population	Hybrids: US 523W	Pfister SX29	DeKalb XL362	Average of 3 hybrids
		kg/ha (15.5% moisture)			
50 cm	40,000	7944	7574	7247	7410
50 cm	50,000	6889	7398	7197	7159
50 cm	60,000	7266	8151	6387	7260
76 cm	40,000	8591	7354	6770	7574
76 cm	50,000	8057	8107	6581	7580
76 cm	60,000	8440	7724	6726	7630
102 cm	40,000	6632	7335	7065	7008
102 cm	50,000	6726	7674	6676	7027
102 cm	60,000	7247	7492	6362	7034
Average for row spacings across all plant populations					
50 cm		7360	7706	6770	7279
60 cm		8359	7731	6688	7593
102 cm		6864	7498	6701	7021
Average for plant populations across row spacings					
	40,000	7718	7417	6851	7329
	50,000	7222	7724	6814	7266
	60,000	7649	7787	6487	7310

Table 10. Corn yields for different row spacings and different plant populations by hybrid, Powhattan, 1968.

Row width	Population	Hybrids: US 523W	Pfister SX29	DeKalb XL362	Average of 3 hybrids
		kg/ha (15.5% moisture)			
50 cm	40,000	7360	8183	7197	7590
50 cm	50,000	7768	8723	7800	8095
50 cm	60,000	7567	8735	7982	7831
76 cm	40,000	7542	8553	6971	7687
76 cm	50,000	7348	8610	7052	7668
76 cm	60,000	7461	8421	7800	7950
102 cm	40,000	6211	7762	6663	6877
102 cm	50,000	7059	7398	6663	7147
102 cm	60,000	7052	7398	7297	7247
Average for row spacings across all plant populations					
50 cm		7561	8547	7655	7837
76 cm		7448	8528	7222	7768
102 cm		6770	7511	6870	7090
Average for plant populations across all row spacings					
	40,000	7034	8164	6939	7379
	50,000	7392	8346	7172	7636
	60,000	7360	8183	7693	7674

Pfister SX29 gave the highest yield, 8735 kg/ha, with the combination of the narrowest row - 50-cm, and highest plant population - 60,000 plants per hectare at Powhattan when compared to all other possible combinations of row width, plant population and hybrid. US 523W had its highest yield, 8591 kg/ha, in 76-cm rows and at 40,000 plants per hectare at Manhattan (Table 9). DeKalb XL362 had its highest yield, 7982 kg/ha, in 50-cm rows and at 60,000 plants per hectare at Powhatten, but at Manhattan its yield dropped to 6387 kilograms per hectare.

Normally yield response of crops including corn is expected to be greater with more moisture, but this did not hold true with US 523W. Highest yield was obtained in 76 cm rows and 40,000 pts/ha at Manhattan (Table 9) where there was less precipitation. No satisfactory explanation is offered for the lower yield at Powhattan except that moisture is only one of the variables involved.

In general there were more consistent yield patterns at Powhattan while at Manhattan fluctuations in yield were greater.

Ears Per Plant

Where records are kept of numbers of ears and plants per plot, it is possible to compute the average number of ears per plant for each entry. The average is a measure of tendency of hybrids to produce more than one ear per plant or their tendency toward barrenness (plants without ears). This is of particular interest in high population tests, since it is well known that some hybrids may have many barren plants at high plant populations.

No significant difference was found among hybrids relevant to the number of ears per plant at Powhattan (Table 11). All hybrids had essentially one ear per plant at Powhattan.

Table 11. Analysis of variance for ears per plant at Powhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	0.06684	
Row width	2	0.02369	1.12
Error (A)	4	0.02117	
Population	2	0.04826	2.99
Hybrid	2	0.02576	1.60
Row width x hybrid	4	0.02501	1.55
Row width x population	4	0.04082	2.53
Population x hybrid	4	0.00586	0.36
Row width x population x hybrid	8	0.02282	1.41
Error (B)	48	0.01613	

In contrast at Manhattan, there were highly significant differences among populations and among hybrids and a significant interaction between population and hybrids for ears per plant (Table 12). This indicates that location affected the response of hybrids to variable plant population. In other words hybrids did not respond in the same pattern at the two locations to the different levels of population.

With the increase of population there was a decline in ears per plant as expected as shown in Table 13. Pfister SX29 on the average maintained the same number of ears at the two higher populations. Ears per plant of US 523W and DeKalb XL362 declined proportionately as plant population increased from 40,000 to 60,000 plants per hectare.

The number of ears per plant is determined by heredity and also by environment. Prolific strains produce multiple ears even under rela-

Table 12. Analysis of variance for ears per plant at Manhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	0.00111	
Row width	2	0.00307	0.18
Error (A)	4	0.01692	
Population	2	0.03975	6.98**
Hybrid	2	0.03427	6.01**
Row width x population	4	0.00485	0.85
Row width x hybrid	4	0.00790	1.39
Population x hybrid	4	0.01946	3.42*
Row width x population x hybrid	8	0.00559	0.98
Error (B)	48	0.00570	

Table 13. Interactive effect between population and hybrids on ears per plant at Manhattan, 1968.

	Hybrid		
Population	US 523W	Pfister SX29	DeKalb XL362
40,000	1.04	0.98	0.96
50,000	0.89	0.99	0.92
60,000	0.89	1.00	0.89
Average	0.94	0.99	0.92

LSD (0.05) among treatments 0.07

tively competitive growth conditions while non-prolific hybrids produce the greatest number of barren stalks at high populations. Second ears might compensate for barren stalks in prolific strains. It may be surmised from the data in Table 13 that Pfister SX29 is population-tolerant while the other two hybrids may be population-sensitive hybrids. In the case of population-sensitive hybrids at high population quite a few plants are barren. These variations among the hybrids could be the result of differences of efficiency in utilizing nutrients and moisture.

Weight Per Ear

A highly significant difference was found in weight per ear among populations and hybrids at Manhattan; a highly significant difference among populations, and a significant 3-way interaction among all three factors for ear weight at Powhattan was observed (Tables 14 and 15).

Table 14. Analysis of variance on ear weight at Manhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	0.00483	
Row width	2	0.00208	2.20
Error (A)	4	0.01032	
Population	2	0.13478	57.33**
Hybrid	2	0.01796	7.64**
Row width x population	4	0.00053	0.23
Row width x hybrid	4	0.00100	0.43
Population x hybrid	4	0.00133	0.56
Row width x population x hybrid	8	0.00160	0.68
Error (B)	48	0.00235	

Table 15. Analysis of variance on ear weight at Powhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	0.00066	
Row width	2	0.02030	2.27
Error (A)	4	0.00896	
Population	2	0.09002	36.42**
Hybrid	2	0.00516	2.09
Row width x population	4	0.00234	0.95
Row width x hybrid	4	0.00162	0.66
Population x hybrid	4	0.00542	2.19
Row width x population x hybrid	8	0.00580	2.35*
Error (B)	48	0.00247	

Hybrids that tend to have more than one ear per plant may have ears of below average weight. Thus, ear weights given are not always directly related to yield but are of interest in relation to other studies involving ear size and planting rate.

As shown in Table 16 and Fig. 2 weight per ear was highest at the lowest population regardless of row width. With each subsequent increase of population there was a continuous decline in ear weight. Ear weight was superior in the two narrower rows than in the 102 cm rows.

There were significant differences in ear weight response to changing population among the hybrids (Table 17).

Pfister SX29 had higher ear weight than the other two hybrids at the lowest population, but as plant population increased ear weight of Pfister SX29 declined faster than that of the other hybrids. Hybrids that produce multiple ears will have lower ear weight than single-eared hybrids. In a previous discussion of this experiment it was reported that Pfister SX29 was the best yielder among the 3 hybrids. This might indicate that there is little relation of ear weight to yield. Perhaps, a more correct way to express weight per ear would be to say that weight of grain per plant decreases with increased population. Some hybrids will bear many poorly filled ears at high populations, while others maintain ear weight much better.

As row width widened from 50 cm to 76 cm ear weight increased, but as row width increased further, ear weight declined in all 3 hybrids (Table 18).

Table 16. Interactive effect between row width and population on ear weight at Powhattan, 1968.

Population	Row width		
	50 cm	76 cm	102 cm
		Ear weight (kg)	
40,000	0.25	0.25	0.23
50,000	0.21	0.23	0.19
60,000	0.18	0.20	0.18
Average	0.21	0.23	0.20

LSD (0.05) among treatments 0.05.

Table 17. Interactive effect between population and hybrids on ear weight at Powhattan, 1968.

Population	Hybrids		
	US 523W	Pfister SX29	DeKalb XL362
		Ear weight (kg)	
40,000	0.24	0.25	0.23
50,000	0.21	0.21	0.20
60,000	0.21	0.17	0.19
Average	0.22	0.21	0.21

LSD (0.05) among treatments 0.05.

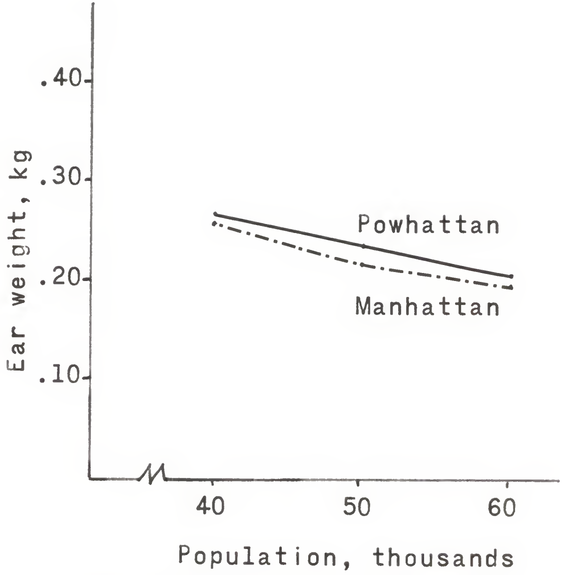

Fig. 2. Ear weight as affected by plant populations and locations.

Table 18. Interactive effect between row width and hybrids on ear weight at Powhattan, 1968.

Row width	Hybrids		
	US 523W	Pfister SX29	DeKalb XL362
		Ear weight (kg)	
50 cm	0.22	0.21	0.20
76 cm	0.24	0.22	0.22
102 cm	0.21	0.20	0.20
Average	0.22	0.21	0.21

LSD (0.05) among treatments 0.05.

Percent Lodging

Since dropped ears and ears on lodged stalks are counted in this experiment, a measure of the total potential yielding capability of each hybrid under individual test conditions was obtained as well as a record of losses due to lodging and ear dropping. Both are important to know when comparing hybrids that differ in maturity because ear losses often increase directly with the time the hybrid is left standing after it matures. Also, such losses often are erratic and may be caused by local conditions or storms not typical of the area or the hybrids the test is expected to represent.

Many factors cause lodging, so resistance to lodging is difficult to measure in an orderly, consistent manner. There were highly significant differences among hybrids in lodging at both locations; a significant difference among populations and a significant 3-way interaction among all the three factors at Powhattan (Tables 19, 20, 21, 22, 23, and Fig. 3).

Table 19. Analysis of variance on lodging at Manhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	3.09	
Row width	2	37.61	2.73
Errow (A)	4	13.76	
Population	2	29.50	1.95
Hybrid	2	460.88	30.41**
Row width x population	4	23.15	1.53
Row width x hybrid	4	17.60	1.16
Population x hybrid	4	11.54	0.76
Row width x population x hybrid	8	18.52	1.22
Error (B)	48	15.16	

Table 20. Analysis of variance on lodging at Powhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	74.40	
Row width	2	66.58	2.61
Error (A)	4	25.49	
Population	2	88.48	3.65*
Hybrid	2	234.92	9.70**
Row width x population	4	31.17	1.20
Row width x hybrid	4	32.20	1.33
Population x hybrid	4	26.36	1.09
Row width x population x hybrid	8	58.50	2.42*
Error (B)	48	24.22	

Table 21. Row width x population interaction on lodging at Powhattan, 1968.

Population	Row width		
	50 cm	76 cm	102 cm
	Lodged plants (%)		
40,000	8.8	2.8	5.0
50,000	7.1	6.1	7.4
60,000	11.0	9.5	6.8

LSD (0.05) 4.6

Table 22. Row width x hybrid interaction on lodging at Powhattan, 1968.

Row width	Hybrids		
	US 523W	Pfister SX29	DeKalb XL362
	Lodged plants (%)		
50 cm	10.3	7.9	8.7
76 cm	11.0	3.8	3.6
102 cm	10.3	6.0	2.8

LSD (0.05) 4.6

Table 23. Population x hybrid interaction on lodging at Powhattan, 1968.

Population	Hybrids		
	US 523W	Pfister SX29	DeKalb XL362
	Lodged plants (%)		
40,000	10.7	2.4	3.4
50,000	9.3	7.1	4.2
60,000	11.5	8.2	7.5

LSD (0.05) 4.6

In Table 21 and Fig. 4 it can be seen that with increase of plant population there was increased lodging. As row spacing narrowed there was a corresponding increase in lodging with highest lodging in the narrowest rows and the highest population.

This occurs because with increased population there is a greater competition among the plants and stalk diameter presumably decreases, and hence becomes more susceptible to lodging.

Lodging ranged from 2.8 to 11.0 percent. Comparing data in Tables 21 and 22 it appears that population effect was greater on lodging than hybrid effect. US 523W lodged at about the same rate at all row spacings while the other two hybrids lodged the most only in the narrower rows, more so in the 50 cm rows (Table 22). US 523W is more susceptible to lodging than the other two hybrids.

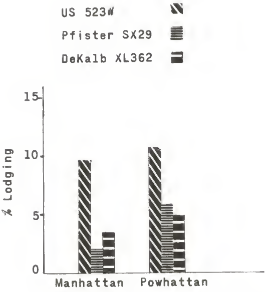

Fig. 3. Lodging percentage as affected by hybrids, two locations.

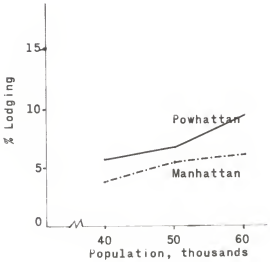

Fig. 4. Lodging percentage as affected by plant populations.

Ear Dropping

Ear dropping of some hybrids could be due to insects or corn borer damage to ear shanks, but some hybrids characteristically drop ears even when borers are absent. It is possible that early hybrids could drop more ears than late maturing hybrids.

Analysis of variance for dropped ears showed no significance at Powhattan,(Table 24) while at Manhattan the difference among hybrids was highly significant (Table 25) and also a significant interaction between population and hybrids was observed (Table 26).

Table 24. Analysis of variance on dropped ears at Powhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	2.56	
Row width	2	2.72	0.47
Error (A)	4	5.82	
Population	2	23.62	2.47
Hybrid	2	21.45	2.24
Row width x population	4	12.01	1.26
Row width x hybrid	4	7.58	0.79
Population x hybrid	4	10.45	1.09
Row width x population x hybrid	8	8.23	0.86
Error (B)	48	9.56	

No consistent trends in dropped ears were evident. Dropped ears ranged from 1.3 percent for Pfister SX29 to 8.8 percent for DeKalb XL362 both medium maturing hybrids. In this experiment DeKalb XL362 matured earliest. Pfister SX29 had the lowest percentage of dropped ears at all population levels.

Table 25. Analysis of variance on dropped ears at Manhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	95.00	
Row width	2	23.05	12.02*
Error (A)	4	1.92	
Population	2	35.38	2.41
Hybrid	2	95.64	6.50**
Row width x population	4	7.57	0.51
Row width x hybrid	4	24.41	1.66
Population x hybrid	4	46.55	3.16*
Row width x population x hybrid	8	10.13	0.69
Error (B)	48	14.71	

Table 26. Effect of plant population and hybrids on dropped ears at Manhattan, 1968.

	Hybrids		
Population	US 523W	Pfister SX29	DeKalb XL362
40,000	4.8	1.8	4.8
50,000	5.3	3.1	1.7
60,000	6.4	1.3	8.8

LSD (0.05) 3.7

Days to 50 Percent Silking

Highly significant differences among hybrids existed for 50 percent blooming date at Manhattan (Table 27) and Powhattan (Table 28).

Normally the difference in length of growing seasons between early and late hybrids is in the number of days from planting to silking, not in the days from silking to maturity, although there was a highly significant difference among the hybrids in percentage of moisture content in this experiment.

Increasing population tends to retard plant development slightly, however, there was no significance for population nor a significant interaction between population and hybrid in this experiment.

DeKalb XL362 silked earliest at both locations (Fig. 5), but at Powhattan was delayed by about 5 days. This may be attributed to the cultivation that was done to control weeds which possibly enhanced evaporation and set back the growth process until enough moisture was restored again by precipitation. It may also have been due to the difference in temperature that existed at the two locations. It is interesting to note that DeKalb XL362, the hybrid that silked earliest, was not the hybrid that dried the fastest.

US 523W, being a full season hybrid, silked the last at both locations (Fig. 5). Although it is a late maturing hybrid it had the highest percentage of lodged plants and dropped ears as discussed earlier.

Table 27. Analysis of variance for days to 50 percent blooming (silking) at Manhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	1.38	
Row width	2	0.61	0.27
Error (A)	4	2.23	
Population	2	2.76	0.74
Hybrid	2	69.36	18.71**
Row width x population	4	4.19	1.13
Row width x hybrid	4	1.12	0.30
Population x hybrid	4	6.68	1.80
Row width x population x hybrid	8	4.73	1.28
Error (B)	48	3.71	

Table 28. Analysis of variance for days to 50 percent blooming (silking) at Powhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	2.12	
Row width	2	0.38	0.27
Error (A)	4	1.42	
Population	2	0.90	1.25
Hybrid	2	301.94	417.18**
Row width x population	4	0.09	0.12
Row width x hybrid	4	1.68	2.32
Population x hybrid	4	0.20	0.27
Row width x population x hybrid	8	0.38	0.53
Error (B)	48	0.72	

Shelling Percentage

Shelling percentage determinations are taken primarily as the basis for converting ear weight to grain weight. An unusually low shelling percentage may indicate a large cob and a slow drying rate. No corrections for moisture percentage of grain or cobs are made in calculation of shelling percentage.

Differences between hybrids were highly significant for shelling percentage at both locations (Tables 29 and 30). At both locations Pfister SX29 had the highest shelling percentage when means of the hybrids were compared (Fig. 6). This, among other merits of this hybrid discussed earlier, probably accounts for its highest yield.

Table 29. Analysis of variance for shelling percentage at Manhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	1.38	
Row width	2	0.61	0.27
Error (A)	4	2.30	
Population	2	2.76	0.74
Hybrid	2	69.36	18.71**
Row width x population	4	4.19	1.13
Row width x hybrid	4	1.12	0.30
Population x hybrid	4	6.68	1.80
Row width x population x hybrid	8	4.73	1.28
Error (B)	48	3.71	

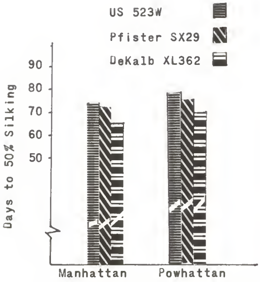

Fig. 5. Days to 50 percent silking of 3 hybrids at two locations.

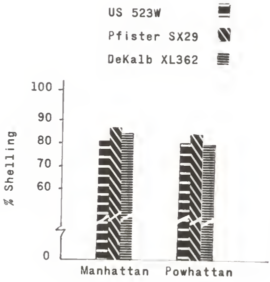

Fig. 6. Influence of plant population on shelling percentage at two locations.

Table 30. Analysis of variance for shelling percentage at Powhattan. 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	10.48	
Row width	2	19.18	1.68
Error (A)	4	11.45	
Population	2	3.74	0.35
Hybrid	2	124.62	11.50**
Row width x population	4	8.00	0.74
Row width x hybrid	4	9.01	0.83
Population x hybrid	4	9.90	0.91
Row width x population x hybrid	8	13.19	1.22
Error (B)	48	10.83	

Moisture Content

Moisture content as a basis for the prediction of maturity is not too reliable. Maturity or physiological maturity is a term used to indicate the time at which maximum dry weight of the grain is attained. Large differences in moisture content at the physiologic maturity among hybrids in one year or for any one hybrid could exist in different years depending upon climatic conditions.

Frequently, grain moisture content at harvest can be used to indicate differences in maturity. Hybrids that mature early and dry quickly are less subject to delayed harvest and consequent losses from many causes. The rate of moisture loss after physiological maturity depends more on the weather than any other factor. Differences between hybrids also are important, since some strains tend to give up moisture more slowly than others. If the ear has reached full dry matter content, frost-kill of the plant, followed by warm, dry weather leads to the most rapid moisture loss without effect on yield.

Any adverse condition in the growth process or maturation that occurs before physiological maturity is reached will delay kernel-fill and delays the drying process.

Hybrid effects on percent moisture were highly significant at both locations (Tables 31 and 32) and also a significant difference among row width at Manhattan was observed. This indicates that there were real differences in their mean moisture percentages.

Table 31. Analysis of variance for percent moisture content at Manhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	73.61	
Row width	2	5.05	7.52*
Error (A)	4	0.67	
Population	2	1.96	0.47
Hybrid	2	25.39	6.03**
Row width x population	4	0.18	0.04
Row width x hybrid	4	3.92	0.93
Population x hybrid	4	1.75	0.42
Row width x population x hybrid	8	4.13	0.98
Error (B)	48	4.21	

Table 32. Analysis of variance for percent moisture content at Powhattan, 1968.

Source of variation	Degrees of freedom	Mean square	F
Replication	2	3.00	
Row width	2	0.12	0.39
Error (A)	4	0.31	
Population	2	0.49	1.14
Hybrid	2	12.33	28.83**
Row width x population	4	0.50	1.17
Row width x hybrid	4	0.63	1.48
Population x hybrid	4	0.37	0.86
Row width x population x hybrid	8	0.46	1.07
Error (B)	48	0.43	

SUMMARY AND CONCLUSIONS

An experiment was initiated to determine the effects of row spacings, plant populations and their interactions on grain yield of corn hybrids at Kansas State Agronomy Farm, Manhattan, and the Cornbelt Experiment Field, Powhattan. The treatments imposed consisted of three row spacings, three plant populations, and three hybrids.

The three hybrids used in the experiments were: US 523W, a full season white hybrid, Pfister SX29, a single cross yellow hybrid, and DeKalb XL362 - a 3-way cross, yellow hybrid, both medium maturing. Row widths were 50, 76, and 102 cm (20, 30, and 40 inches) apart, and plant populations were 40-, 50-, and 60-thousand plants per hectare (16, 20, and 24 thousand plants per acre).

A split-plot design was used in the experiment with row spacings as main plots and the subplots, populations, and hybrids randomized within row spacings. Three replications were used at both locations.

Grain from the various combinations of row width, plant population, and hybrid was harvested and analyses of variance were made on yield, components of yield, maturity (days to 50 percent silking), percent lodging, dropped ears, percent stand, moisture content at harvest, and shelling percent.

Highly significant differences were found for yield among the three hybrids at both locations. Hybrids also differed significantly for components of yield, percentage stand, maturity, dropped ears, lodging, shelling percentage, and moisture content at harvest.

Row spacings and populations did not differ significantly in yield however, there were highly significant differences among populations on ear weight and ears per plant. There was a significant row width by hybrid interaction on yield.

Interrelationships among yield components indicate that yield per plant was inversely associated with population per unit area. Plot yields, on the other hand, were directly associated with number of plants per unit area and inversely associated with ear weights.

A substantial yield increase was obtained as row width was narrowed from 102 cm to 76 cm to 50 cm (40 inches to 30 inches to 20 inches). This was particularly evident at Powhattan where moisture was more favorable. Averaged over hybrids and populations 50-cm rows at Powhattan had 0.8 and 9.5 percent or 69.1 and 734.6 kg/ha yield advantage, respectively over the 76- and 102-cm rows. One-hundred-two cm (40-inch) rows at both locations resulted in considerably lower yields when compared to the narrower rows.

Two of the three hybrids - Pfister SX29 and DeKalb XL362 - yielded highest in the narrowest rows, 8735 kg/ha (139.1 bushels per acre) and 7982 kg/ha (127.1 bushels per acre), respectively. These yields were obtained at the highest population, 60,000 plants/ha, at Powhattan. US 523W yielded highest, 8591 kg/ha (136.8 bushels per acre) in 76 cm at 40,000 population at Manhattan.

Analysis of these data within the limits of the experiments and the hybrids used can be interpreted to mean that decreasing row width in itself resulted in no significant increase in yield, increasing populations increased yield appreciably where moisture was adequate.

Proper combination of hybrid, moisture level, plant population, and row width are necessary to produce corn for maximum profit. The real challenge, of course, is to determine the proper combination for each grower.

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THE EFFECT OF ROW WIDTH AND PLANT POPULATION ON GRAIN YIELD, YIELD COMPONENTS, AND OTHER CHARACTERISTICS OF THREE CORN (*Zea mays* L.) HYBRIDS

by

ZEWUDU OUMER

B. S., Haile Sellassie I University, Ethiopia, 1966

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Corn (*Zea mays* L.) yield is a function of climate, soil, variety (hybrid), spacing, and plant population. Correlating these functions to produce the highest possible yields with greatest efficiency has been the aim of research workers and farmers everywhere since corn production began. The dynamics that influence the interactions of these functions are difficult to control and this limits the findings of research to a specific range of conditions.

To evaluate the effects of row width and plant population and their interactions on corn yield, three hybrids were tested at the Kansas State Agronomy Farm, Manhattan, and the Corn belt Experiment Field, Powhattan. Three row widths and three populations were used.

The three hybrids used in the experiment were: US 523" - a full season white hybrid, Pfister SX29 - a single cross yellow hybrid, and DeKalb XL362 - a 3-way cross yellow hybrid, both medium maturing. Row widths were 50, 76, and 102 cm (20, 30, and 40 inches) apart, and plant populations were 40-, 50-, and 60-thousand plants per hectare (16-, 20-, and 24-thousand plants per acre).

A split plot design with row spacings as main plots and populations and hybrids as subplots was used. Three replications were used at both locations.

Grain from the various combinations of row width, plant population, and hybrid was harvested and analysis of variance was made on yield, components of yield, maturity, percent lodging, dropped ears, stand establishment, moisture content at harvest, and shelling percent.

A highly significant difference among hybrids existed for yield at both Manhattan and Powhattan. Hybrids were also significant for components of yield, percentage stand, lodging, dropped ears, moisture content, and shelling percentage.

Row spacings and populations did not differ significantly in yield, however, there were highly significant differences among populations on ear weight and ears per plant. There was significant row width by hybrid interaction on yield. The number of ears per plant was affected more by population than by hybrid, decreasing as population increased. Weight per ear also decreased as population increased.

Averaged across all populations and hybrids yields were 7279, 7593, and 7021 kg/ha (115.9, 120.9, and 111.8 bushels per acre), respectively for 50, 76, and 102 cm (20, 30, and 40 inch) rows at Manhattan. At Powhattan they were 7837, 7768, and 7090 kg/ha (124.8, 123.7, and 112.9 bushels per acre), respectively for 50-, 76-, and 102-cm rows. Yields for plant populations at Manhattan were 7329, 7253, and 7310 kg/ha (116.7, 115.5, and 116.4 bushels per acre), respectively for 40-, 50-, and 60-thousand plants/ha. At Powhattan they were 7379, 7636, and 7674 kg/ha (117.5, 121.6, and 122.0 bushels per acre) in that order for 40-, 50-, and 60-thousand plants/ha.

Weather influences crop yields and corn is not an exception. Corn grown in narrower rows at Powhattan where moisture was more favorable resulted in higher yield at the highest population.