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The effect of potassium on ear fill of high density corn (Zea mays, L.).

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THE EFFECT OF POTASSIUM ON EAR FILL OF

HIGH DENSITY CORN (ZEA MAYS, L.)

A Thesis Presented

by

Maureen Crowley Tumenas

Submitted to the Graduate School of

University of Massachusetts in partial fulfillment

of the requirements for the degree of

Master of Science

February 1981

Department of Plant and Soil Science
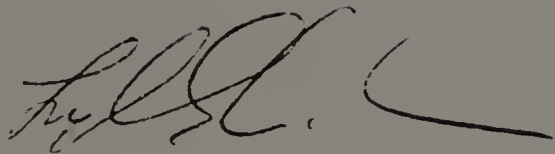
The Effect of Potassium on Ear Fill of

High Density Corn (<u>Zea</u> <u>mays</u>, L.)

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By

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INTRODUCTION

Total grain yield of hybrid corn, (Zea mays, L.) increases as plant density increases until the plant density itself becomes a stress factor on growth, and yield decreases. The density at which this stress becomes evident varies with the corn variety, the cultural practices, and the environmental conditions of a particular growing season. Above this maximal density, the grain yield per plant decreases because the ears on a plant are generally smaller and the kernels on the tip of the ear are not filled. However, since there are more plants per unit area, grain yield per hectare generally continues to increase with high plant densities to a theoretical maximum yield, above which the decreased yields per plant result in a decreased grain yield per hectare.

The observed reduced ear size and smaller kernels at the ear tip in corn grown at high population densities are probably due to limited availability of soil nutrients, water and light to individual corn plants. Decreased availability of any of these constituents in the plant environment would slow the photosynthetic process, leaving little carbohydrate for growth and development of the plant, thus decreasing potential

translocation to the corn ear.

Corn plants grown at high population densities have been shown to have less leaf area per plant, decreased stalk diameters, higher lodging percentages and a higher proportion of barren stalks, compared with corn plants grown at low population densities (1,4,6,7,8,12, 26). Corn plants grown at high population densities exhibit greater moisture stress and nutrient deficiencies compared with plants grown at lower population densities (3,5). Research indicates that high density corn plantings tend to silk later than low density plantings, allowing less time for growth and development of kernels on the ear (8,21,34).

Poneleit and Egli (35) reported the effective grain filling period duration (EFPD) to be up to 2.5 days less at high plant densities as compared with low plant densities. Wilson and Allison (48) indicate that ears are initiated later and fewer primordia produce fully developed florets. Of those florets produced, in corn grown at high density, fewer produce viable silks during pollen shed (48).

Potassium may be a limiting factor in kernel development on ears of corn grown at high densities. Preliminary research at Iowa State University (19) has indicated that potassium plants an important role in kernel fill at high population densities. In a study by Bohling and Webb (3), potassium applications of 90 kg per hectare

on corn grown at the rate of 79,040 plants per hectare (pph), increased corn ear fill as compared with no additional potassium at 79,040 pph. Peaselee et al. (31) reported accelerated development to silking and delayed grain maturity with potassium gertilizer additions up to 224 kg per hectare. These workers also reported a higher leaf area index at 224 kg of potassium per hectare as compared with controls receiving no additional potassium, and this provided a greater degree of light interception by the leaves, reduced silking delay, and extended the EFPD.

Potassium fertilization tends to delay leaf senescence, which is important in maintaining an adequate photosynthate source for translocation to the developing grain. There is also some evidence that potassium may delay grain maturity, thereby extending the EFPD. Peaslee et al. (31) report an increase in grain yield correlated with an increase in EFPD.

The major objective of this research was to examine the effects of potassium on yield and yield components in corn grown at high densities with specific attention to the development of kernels on the tip of corn ears.

C H A P T E R   II
LITERATURE REVIEW

Corn yields have been shown to be increased by
increasing the plant populations up to a point where
stress due to the density of plants actually reduces the
grain yield (1,4,6,7,8,12,26).

Donald (6) found that the highest grain yields
in corn occur approximately at a plant density where bio-
logical yield is maximum. At this maximum biological
yield a gain in total yield per hectare due to addi-
tional plants is offset by a decrease in grain yield per
plant. Donald (6) concluded that these conditions are
due to either limiting light or nutrients causing both
competition among plants and within plants at critical
periods of development.

Many factors affect kernel fill and development.
Light interception, leaf area index, leaf area duration,
moisture and nutrient availability have all been shown
to affect development. Aldrich (1) has indicated that
stress conditions within the plants, or occasionally
poor timing of pollen shed and silk receptiveness may
cause poor kernel set.

Moss and Stinson (27,28) found that shading

induced barrenness in corn, probably due to poor silk devel-
opment. Schmidt and Colville (40) reported reduced grain
yields in corn when they artificially shaded lower leaves
to simulate field conditions of high density. Zierserl et
al. (51) related lower nitrate reductase activity in shaded
corn plants to reduced grain yields. Prine and Shroder
(37) optimized nutrient and moisture levels in corn grown
under simulated field conditions, and concluded that light
is the limiting environmental factor in corn grain yield.

However, not all workers agree. Miller (26) has
shown that some corn varieties do not decrease growth
when shaded, and he concluded that light was not a crit-
ical factor in development. Moss and Stinson (27,28)
also reported large growth differences when comparing the
responses of different corn varieties to shading.

Numerous experiments have been conducted to deter-
mine the role of various leaf area indexes (LAI) and leaf
area durations (LAD) in high plant densities on corn
grain yields. Eik and Hanway (9,10) indicated grain yield
was directly correlated with LAI at silking and with LAD.
They reported an optimum leaf area index, above which
grain yield per plant declines with increasing popula-
tion. LAD varied with the hybrid, but was influenced by
available nutrients. From this evidence, Eik and Hanway
(9,10) concluded that the yield of grain is linearly
related to LAI at silking and to LAD over the grain

filling period. They indicated that factors affecting plant growth also affect the early establishment and longevity of leaf area, therefore affecting yield.

Other experiments have been conducted on selectively defoliated corn. Most of this work points to a sink limitation of grain yield (12,18,32,40,49). However, Tollenaar and Daynard (45) reported a source limitation for corn yield, where neither shading nor light enrichment affected LAI or LAD. From their data they concluded that grain yield may be increased by increasing leaf area per plant or by extending LAD after flowering.

Silking delay, possibly correlated with moisture stress, is one of the problems associated with high population density corn. Denmead and Shaw (5) reported moisture stress prior to silking reduced grain yields by 25%. Moisture stress at silking caused a 50% reduction in grain yield, and continued moisture stress after silking reduced corn grain yields by 21%. The moisture stress also caused a relative reduction in cob length, leaf area and net assimilation. From these data, they (5) concluded that (a) early stress affects the size of the assimilating surface at ear development, and (b) stress after ear emergence has a direct effect on grain yield. Research has shown that corn grown in narrow rows at high populations uses water more efficiently than corn grown at lower populations with wider rows (50). This

evidence suggests that silking delay associated with moisture stress at high densities, may be alleviated by using narrower rows.

Silking is generally delayed more than tasseling in corn grown at high plant population densities. Dungan (8) found that the interval between silking and tasseling was approximately one day greater at 49,420 pph than at 19,768 pph. Poneleit and Egli (35) reported a 2.5 day delay at 45,302 pph as compared with 11,325 pph. Kohnke and Miles (21) concluded that silking is delayed one day for each addition of 8,650 to 10,000 pph.

Sass and Loefful (39) reported that competitive pressure does not produce a marked retardation of ear elongation, ovary development or silk elongation until approximately 74 days after planting. Wilson and Allison (48) reported that competitive pressures affect ear differentiation and development much earlier in the life cycle.

Work by numerous investigators (1,6,9,10,43) has suggested that increasing the efficiency of light interception, increasing LAI and LAD, or relief of moisture stress at silking, could theoretically increase corn grain yields at high population densities. Potassium has been shown to increase leaf area (25), prolong the EFPD (31), and to effect stomatal closure (20).

Potassium has a direct effect on net photosynthesis

(27). A lack of potassium, well above 'critical potassium levels', affects stomatal closure and thereby decreases the photosynthesis rate. Potassium deficiency causes an early firing of lower leaves, thus reducing the photosynthetic efficiency, and lowering both LAI and LAD, which have been shown to affect corn grain yields. In addition to delaying leaf senescence, potassium additions may stimulate greater leaf area, thus increasing the potential for photosynthesis and adequate photosynthate source for translocation to grain (25). Potassium plays an important role in the water economy of the plant, possibly alleviating moisture stress at critical growth stages (36).

·MacLeod (24) found that potassium, among the major fertilizer elements, had the greatest effect on yields of barley heads, straw and grain, at each stage of development. Potassium had the greatest effect on kernel weight.

Poneleit and Egli (35) reported that kernel dry weight accumulation rate of corn was not affected by plant density; however, since the EFPD was less at higher densities, the smaller kernels and reduced number of kernels caused a 20% yield reduction per plant at the higher population.

Peaslee et al. (31) reported that potassium accelerated development to silking and delayed grain maturity of corn. This evidence indicated a longer EFPD, which did increase corn grain yields, probably due to enhanced growth

of kernels on the tips of the ears, as well as shortening the interval between tasseling and silking.

Hanway (13) indicated that potassium is important for proper development of the corn ear. He reported that any deficiency of nutrients, such as potassium, during silking and grain fill would result in unfilled kernels and 'chaffy' ears.

In summary, research has indicated that some of the factors involved in kernel fill and development may be light interception (26,27,28,37,40,51); LAI and LAD (9,10, 42); and moisture (5,8,21). Potassium has been shown to influence light interception by affecting leaf area (25), to influence LAD and senescence by its effect on carbohydrate metabolism (23) and to influence the moisture status and photosynthetic efficiency of the corn plant by affecting guard cell behavior and stomatal closure (28).

C H A P T E R   I I I

MATERIALS AND METHODS

Plant Materials

A silage corn (<u>Zea</u> <u>mays</u>, L.), cultivar Wisconsin
335A[1] (2100 degree days) (2), was planted and grown on a
fine sandy loam at the experimental research farm in South
Deerfield, Massachusetts in 1978. The field was fertil-
ized and limed with 900 kg 10-10-10 per hectare and 3400
kg limestone per hectare, respectively, one week before
planting.

Seed was planted on May 22, with a two row corn
planter, in north-south oriented rows, 71 cm apart. Seed
spacing was approximately 13 cm. Since initial seed
germination was poor, corn was reseeded by hand, where
necessary, two weeks after planting. Replanting was done
to establish plants approximately 7-8 cm apart to
accomodate an additional plant density. The plantings
were thinned three weeks after seeding to establish pop-
ulation densities of 49,420; 74,130; 98,840 and 148,260
pph in randomly selected plots. Seedlings from the initial

_____

[1]Seed was donated by Agway, Inc., Syracuse,
New York.

planting were labelled at this time to identify plant populations of the same developmental stage at harvest.

Each plot was 10.7 meters by 4.9 meters with 7 rows of corn (Figure 1). Potassium levels were established by banding potassium by hand, 5 cm to the side and 5 cm below newly established seedlings (Stage 1, according to the procedure of Hanway (13)). Potassium treatments were applied as muriate of potash (60%) at a rate of 90 kg potassium per hectare. Each plot, consisting of seven rows of corn, was divided into a 3 row potassium treatment, a 3 row check (no additional potassium) and a guard row. The 3 rows on each side of the middle guard row were selected for the potassium treatment or the check.

Nitrogen was sidedressed by hand as NH_4NO_3 at 56 kg nitrogen per hectare, four weeks after planting, (Stage 1.5, according to Hanway (13)).

Weeds were controlled by hand spraying a 2% solution of atrazine (43% a.i.) at a rate of 280 liters per hectare. Few weeds were observed in plots throughout the growing season.

Experimental Design

The experimental design was a randomized split plot, with four plant densities and two levels of potassium fertilization.

Figure 1. Field Plot Design. Plant density was randomly assigned (except "D", which was selectively located in the NW end of the field due seed germination pattern). Plots were 10.7m by 4.9m, with 7 rows of corn per plot, oriented in a north-south direction. Row spacing was 71cm, with plant spacing according to density. There were 5 replicates of densities A through C, and 3 replicates of density D. Plots were divided into 3 check rows, 1 central guard row and 3 treatment rows.

Figure 1. Field Plot Design

Figure 1. Field Plot Design
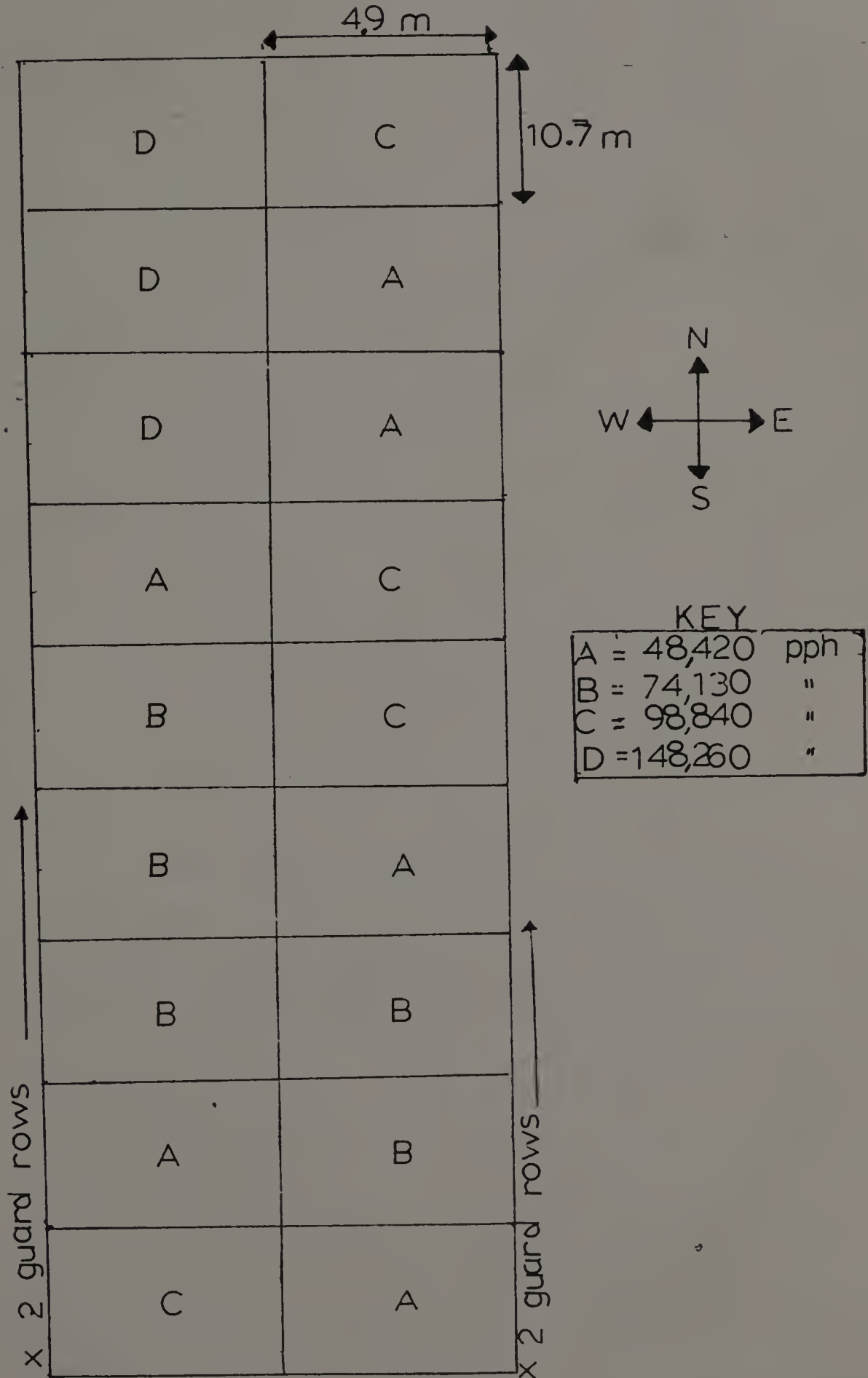
The plant densities were 49,420; 74,130; 98,840 and 148,260 plants per hectare. Five replicates, randomly placed, of the three lower densities were used. Due to insufficient seed germination, only three replications of the highest plant density, 148,260 pph, were available, and these were grouped on the northwest corner of the experimental plot. Treatments were (1) no additional potassium added and (2) 90 kg per hectare additional potassium.

Sampling Technique

Yield determinations were done on ten plants per treatment, selected and labelled 7 weeks after planting. This method of yield determination insured samples of the same developmental stage at harvest, since two plantings had been made. Plants selected for yield determinations were not included in any type of destructive sampling until harvest. All samples taken during the growing season were obtained from the center row of each three row treatment, approximately two meters north of the plants selected for yield trials. No destructuve samples were taken of plants in the two bordering rows in order to maintain canopy leaf area index and plant density stress.

Leaf areas, for calculating leaf area portion (LAP) and area of the ear leaf at silking, were measured with a portable leaf area meter (Model LI-3000, Lamda Instrument

Corp., Lincoln, Nebraska) with measurements taken on three leaves (ear leaf and two attending leaves) of three plants per treatment (9 leaves total per treatment). The sum of the leaf areas of these three leaves was called leaf area portion (LAP) after Stickler (42).

Plant leaf area (PLA) was calculated using three different methods. In the first method, leaf areas were measured on all leaves from ten plants from each potassium treatment at each plant density. A total of eighty plants were measured, ten plants from eight plots. An average PLA was determined for each of the measured plots by adding the leaf areas of the ten plants and dividing by ten to obtain a mean PLA. The average PLA was divided by the average area of the ear leaf to give a leaf area factor (LAF) after Francis et al. (11). To obtain PLA for each treatment the area of the ear leaf at silking (mean of 3 observations) was multiplied by the LAF which had been calculated for each treatment. This method of calculating PLA appeared to be valid, in that the calculated PLA was highly correlated with the actual PLA measured. Leaf area index was calculated as [(PLA)(no. of plants/land area)].

In the second method, PLA was calculated as the area of the ear leaf at silking multiplied by 9.36(LAF), after Pearce et al. (30). This method also appeared to be valid, since the PLA obtained in this manner was highly

correlated with the actual PLA and with the PLA calculated in the first method. Leaf area index was calculated as in the first method.

In the third method, PLA was calculated as the mean of the LAP multiplied by LAF calculated in the first method, or by using the LAF of 9.36 of Pearce et al. (30), as in the second method. PLA calculated in this manner was highly correlated with the PLA calculated in both the first and the second methods as well as with the actual PLA.

Since all the methods used for calculating PLA were highly correlated with the actual measured PLA, values obtained in the first method (Francis et al. (11)) were used in this study. This method was selected because the correlation with the actual PLA was slightly higher, (r value=.97, as compared with the second method, r=.95, and the third method, r=.89).

For fresh and dry weights samples of three whole corn plants per treatment were taken seven weeks after planting, weighed, oven dried at 70°C for two days, and then reweighed. Subsequently, samples of the ear leaf and the two attending leaves, one above and one below the ear, were taken every 10 days until harvest (126 days after planting). Fresh and dry weights of the leaf samples were obtained in the same manner as above. Dry matter, moisture, and N,P,K,Ca, and Mg

content of the leaf tissue were determined in both the whole plant and the leaf samples. Whole plant and leaf samples were ground in a Wiley mill (40 mesh) and subsamples were used for mineral analyses.

Pollen samples were taken once a week during active pollen shed (10th and 11th weeks after planting) and planted on an agar growth medium (33) to provide pollen viability data. Pollen tube growth and percent pollen germination were recorded.

Lodging, barren plants, leaf senescence, and the intervals between tasseling and silking and from silking to maturity were monitored daily to determine any effects of plant density or potassium treatment.

Total nitrogen content of leaf samples was determined by the micro-Kjeldahl test (44). Potassium, magnesium and calcium content of leaf samples were determined by atomic absorption spectrophotometry. Phosphorus content of leaf samples was measured colorimetrically at 882 nm by the reduction of ammonium-molybodiphosphate complex by ascorbic acid (46).

At the harvest date (September 25, 126 days after planting) all plants had reached physiological maturity, (Stage 10, according to Hanway (13)). Fresh weight of the husked ear, stover, and the number of ears per each ten plant sample were recorded. The corn stover was chopped with a portable corn chopper and 0.91 kg

samples were taken to determine moisture content. All harvested samples were weighted as before and oven dried at 70°C for four days.

Ears at harvest were evaluated for individual fresh and dry weight, moisture content, length, diameter 5 cm from the base, kernel weight and kernel number per row. Ear fill was determined by measuring both the length of the unfilled portion of the ear and the proportion of the unfilled length in relation to the length of the ear.

$$\% \text{ Fill} = [\frac{(\text{Total ear length} - \text{Unfilled ear length})}{\text{Total ear length}} \times 100]$$

Yields were calculated as silage yield at 70% moisture, stover yield at 70% moisture and grain yield as shelled no. 2 corn at 15.5% moisture.

C H A P T E R   IV

RESULTS

Plant density and potassium fertilization had significant effects on yield and yield components, as well as leaf area index and the mineral concentration of the ear leaf at silking. Grain yield was directly correlated with plant density (Figure 2), and increased linearly as plant density increased (r^2 = 0.7, p = .001). Grain yield was also linearly correlated with leaf area index at silking (r^2 = 0.71, p = .001), (Figure 3). Yield of grain per plant decreased as plant density increased and a significant linear trend was indicated.

Yields of stover and corn silage were highly correlated with plant density (Figures 4 and 5). As plant density increased both stover and silage yield increased linearly (r^2 = 0.94 and 0.89, respectively, p = .001). Stover yield per plant decreased as plant density increased and a significant linear trend was indicated.

Potassium fertilization had no significant effect on grain yield, nor on yields of silage or stover. Neither plant density, nor potassium treatment had any

Figure 2. The effect of plant density on grain yield of corn.

The chart shows grain yield (BU/A) on the y-axis with values 70, 90, 110, 130, 150, 170, and plant density (pph) on the x-axis with values 0, 48,420, 74,130, 98,840, 148,260.

$$\hat{Y} = 41.07 + .00078(x)$$

$$r^2 = .72$$
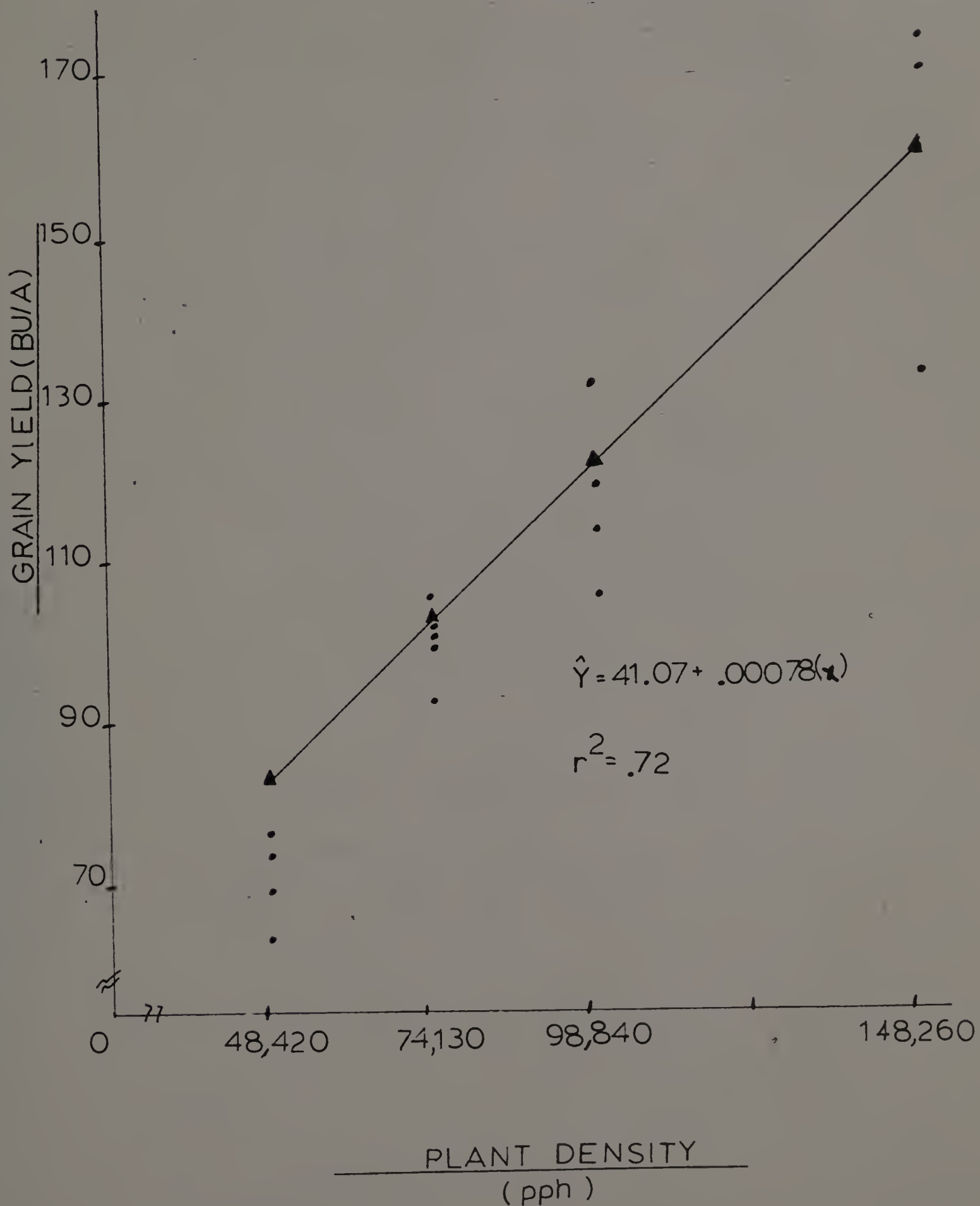
Figure 3.   The effect of LAI on grain yield of corn.

$$\hat{Y} = 59.30 + 25.82(x)$$

$$r^2 \doteq .71$$
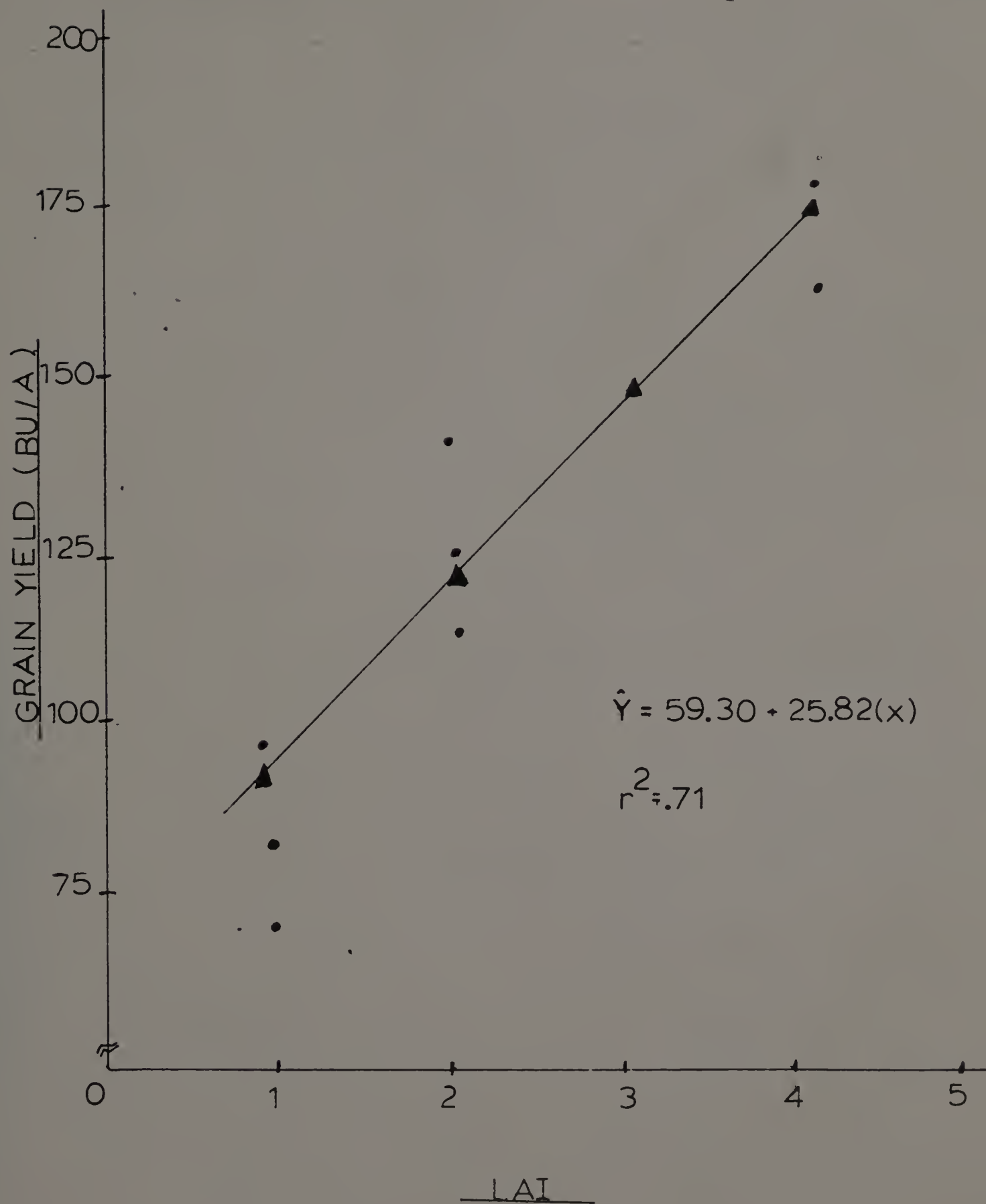
Figure 4. Effect of plant density on corn stover yield.

$\hat{Y} = 2.64 + .00014(x)$

$r^2 = .94$
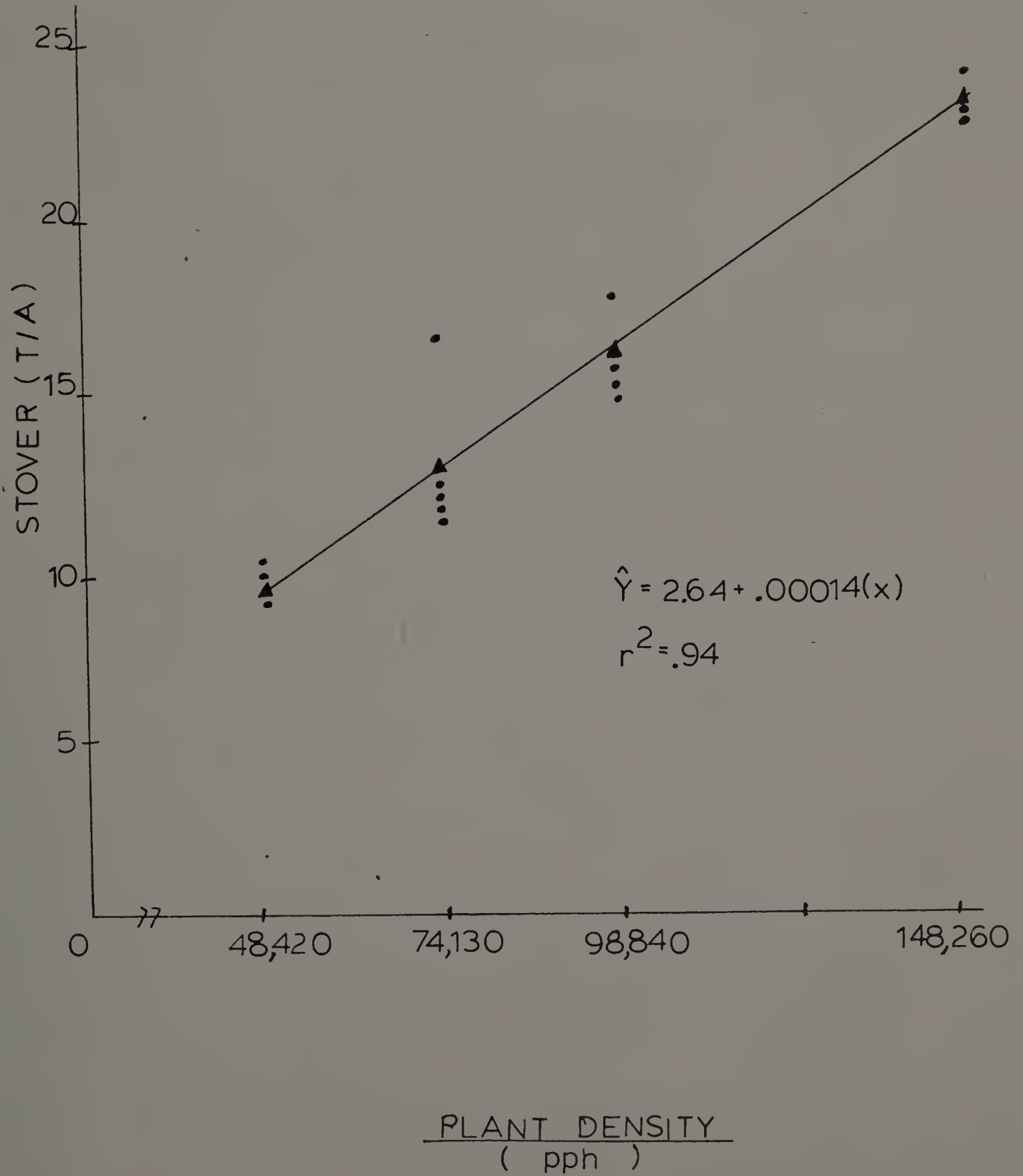
Figure 5. Effect of plant density on corn silage yield.

$\hat{Y} = 9.11 + .00026(x)$

$r^2 = .89$
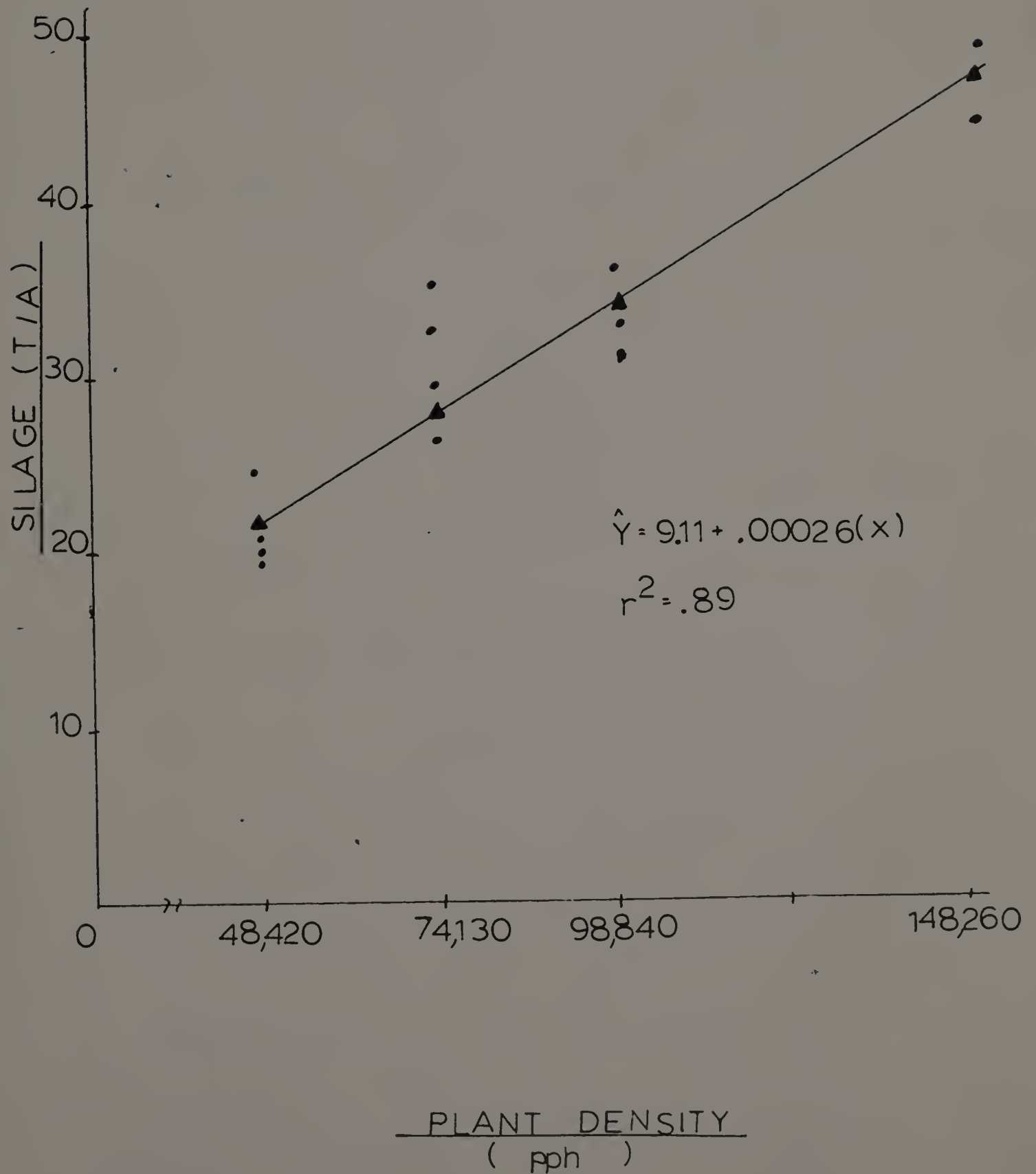
significant effect on ear fill, or on the number of ker-
nels per row, ear diameter, or the number or percentage
of nubbins per ten plants. Plant density did effect
the number of ears per ten plants, the ear length, and
the ear weight (Tables 1 and 2). The number of ears per
ten plants, the ear length, and the ear weight decreased
as plant density increased. A significant linear trend
was indicated.

Leaf area index was directly correlated with plant
density (Figure 6). Leaf area increased to 3.76 as plant
population increased to 148,260 pph. There was a linear
relationship ($r^2 = 0.99$, $p = .001$), between LAI and plant
density. Higher potassium levels decreased LAI signifi-
cantly (Table 3). The mean LAI in plant densities with
total applications of 90 kg per hectare potassium was
2.00 as compared with a mean LAI of 1.95 with 180 kg
potassium per hectare.

Leaf area of the ear leaf at silking increased
slightly as plant density increased from 49,420 to
98,840 pph, but this trend was not significant (Table 4).
Leaf area decreased with increased potassium fertiliza-
tion; however, this response varied with plant density
(Table 4).

Plant density had no significant effect on
the percent potassium or the percent magnesium in the
ear leaf or two attending leaves at silking. Neither

TABLE 1

DENSITY EFFECTS ON EAR FILL COMPONENTS

Variable	Density (pph)				Trend	SE
	48,420	74,130	98,840	148,260		
% Fill	88.32	87.37	88.74	83.78	n.s.	1.981
Unfilled length	1.81	1.83	1.73	2.00	n.s.	0.215
No. kernels/row	33.8	31.4	32.9	25.7	n.s.	1.555
Ear wt. (g)	155.93	136.99	144.07	126.06	1	8.163
Ear diam. (cm)	4.46	4.31	4.40	4.26	n.s.	0.073
Ear length (cm)	17.18	16.26	16.73	15.04	1	0.590
No. ears/10 plants	10.5	11.1	9.9	9.4	1	0.347
No. nubbins/10 plants	0.6	1.4	0.3	1.0	n.s.	0.530
% nubbins/10 plants	5.3	10.9	3.3	11.5	n.s.	4.537

TABLE 2

POTASSIUM EFFECTS ON EAR FILL COMPONENTS

Potassium level (Kg/h)	% Fill	Unfilled length	No. kernels/row	ear wt. (g)	ear diam (cm)	ear length (cm)	no. ears/ 10 plants	no.nu- bbins/ 10 plants	% nub- bins/ 10 plants
90	86.93	1.79	32.9	144.58	4.34	16.46	10	.78	8.1
180	87.18	1.84	29.8	135.44	4.36	16.15	10.43	.88	7.5
Probability of Differ- ence	.954	.567	.350	.246	.978	.565	.417	.861	.846

Figure 6. Effect of plant density of corn on LAI.
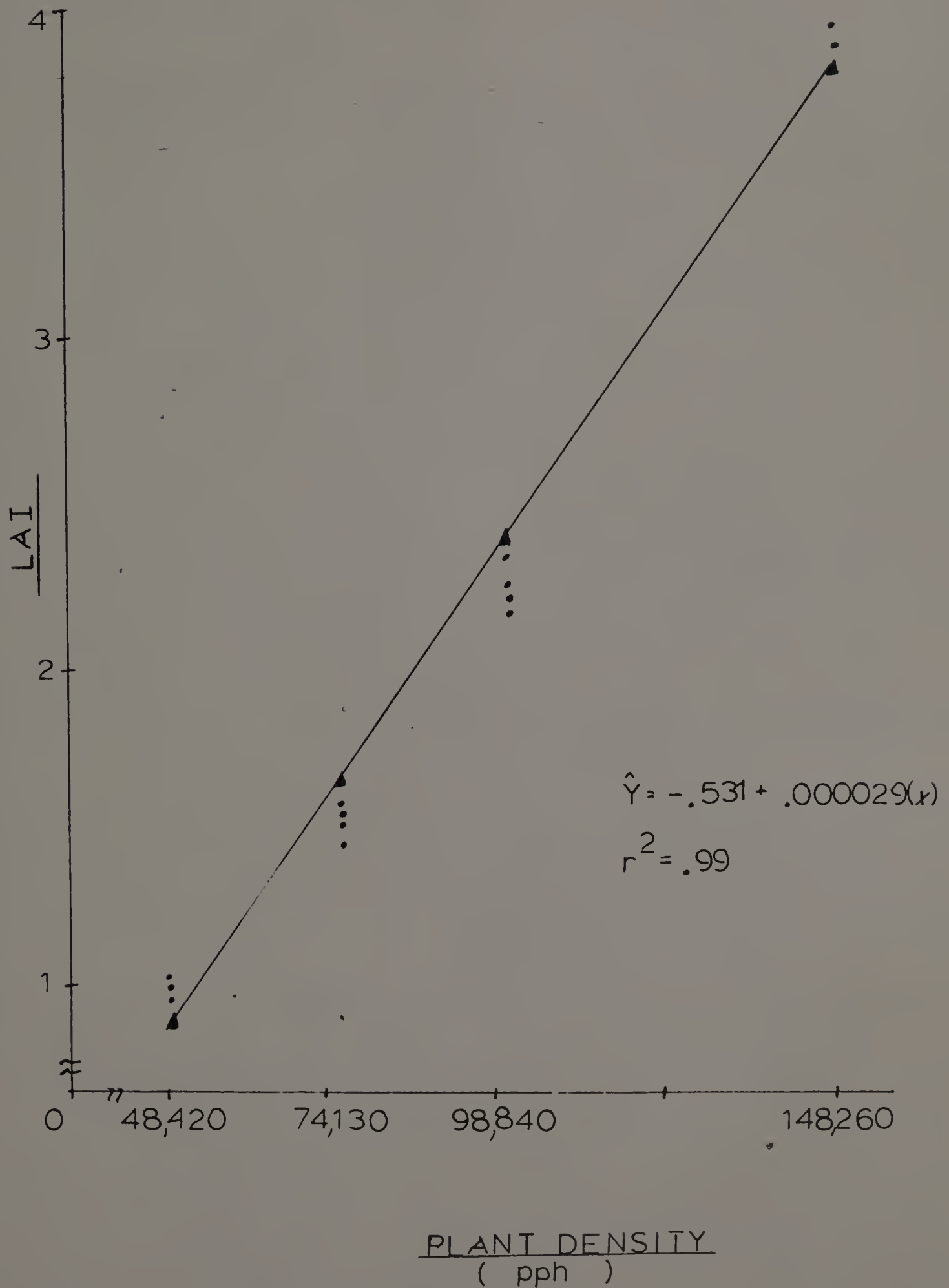
TABLE 3

EFFECT OF POTASSIUM FERTILIZATION ON NUTRIENT CONTENT, LAI, STOVER MOISTURE AND DRY WEIGHT OF ZEA MAYS, L.

Total K Applied (kg/h)	% K[1]	% Ca[1]	%K/%Ca	%K/%Mg	LAI[2]	%Moisture[3] Stover	Stover[3] Dry Wt. (kg)	Leaf[4] Dry Wt. (g)
90	2.64b	2.55a	10.65b	13.25b	2.00a	73.83b	0.24a	14.33a
180	2.90a	2.26b	13.30a	16.43a	1.95b	75.81a	0.22b	12.84b

Means within columns followed by unlike letters are significantly different at the 5% level. Mean separation by LSD.

[1]Nutrient analyses of 1° ear leaf at silking.

[2]LAI mean of whole plant samples at silking.

[3]Stover moisture and dry weight of 0.91 kg fresh weight sample at harvest.

[4]Dry wt. of 3 ear leaves/at silking treatment.

TABLE 4

EFFECT OF PLANT DENSITY AND POTASSIUM ON 1° EAR LEAF AREA OF CORN

Plant Density (pph)

Total K applied (Kg/h)	49,420	74,130 (leaf area [1] (cm²))	98,840	148,260	Mean
90	79.39a	72.13a	69.98b	69.68a	70.99
180	65.52b	68.79b	72.00a	65.42b	68.64
Mean	69.45	70.35	70.99	67.55	69.81

Means within columns followed by unlike letters are significant different at the 5% level by L.S.D.

[1] Leaf area at silking.

plant density nor potassium fertilizer addition had any significant effect on the level of nitrogen or phosphorus. The level of potassium fertilizer applied did affect the %K, %Ca and the K/Ca and K/Mg ratios of the corn leaves.

Potassium additions of 180 kg per hectare as compared to 90 kg per hectare, increased the percent potassium from 2.64 at the lower potassium level to 2.90 with the higher potassium level (Table 3). The potassium fertilization rate of 180 kg per hectare decreased the percent calcium from 2.55 at 90 kg potassium added, to 2.26 with the higher level of potassium (Table 3). The ratio of %K/%Ca in the leaf tissue was increased significantly with the higher rate of potassium to 13.30 with 180 kg potassium.

The percent magnesium was not significantly affected by the level of potassium fertilization used, although a trend was indicated that the percent magnesium decreased with potassium addition, this trend was not significant. The %K/%Mg ratio increases as potassium fertilization increased. With the higher level of potassium, 180 kg potassium per hectare, the %K/%Mg ratio was 16.43 as compared with 13.25 with 90 kg potassium per hectare added, (Table 3).

The EFPD was affected by plant density, but not by potassium. As plant density increased, EFPD de-

creased (Table 5). Compared with the 49,420 pph population
of a 5 day decrease of EFPD was observed in populations
of 148,260 pph, a 2 day decrease in EFPD with populations
of 98,840 pph and a 1 day decrease in densities of
74,130 pph.

Stover moisture content and corresponding dry
weights were affected by potassium fertilization levels
(Table 3). Plant density had no significant effect. The
higher level of potassium (180 kg per hectare), signif-
icantly increased the moisture content of the stover to
75.81% as compared with 73.83% at the lower level of
potassium (90 kg per hectare). There was a corresponding
decrease in stover dry weight with increased potassium.
Stover dry weight (in the original 0.91 kg fresh weight
sample) decreased from 0.24 kg at 90 kg potassium per
hectare to 0.22 kg with 180 kg potassium per hectare.
Dry weight of the three ear leaves per treatment at
silking was significantly reduced by potassium fertil-
ization (Table 3). Plant density had no significant
effect on the leaf dry weight. The higher level of
potassium decreased leaf dry weight from 14.43 g, at
90 kg potassium per hectare to 12.84 g with 180 kg
potassium per hectare.

TABLE 5

PLANT DENSITY EFFECTS ON EFPD

Density (pph)	EFPD (days)	EFPD (as compared to lowest density)
49,420	58	-
74,130	57	1
98,840	56	2
148,260	53	5

C H A P T E R   V

DISCUSSION

Neither plant density nor potassium had any sig-
nificant effect on ear fill. LAI was correlated with
plant density and grain yield. Plant density appears to
effect yield and EFPD. Potassium treatment decreased
LAI and calcium uptake, and increased stover moisture
content.

Due to poor germination of the initial seeding,
some corn seed was replanted by hand in this study to
establish plants 7-8 cm apart. Although plants from
the initial planting were used for all measurement, the
replanting may have affected plant density stress since
the replanted plants were smaller than those of the
initial planting. In some cases the corn plants used
for measurements were growing next to plants which
were less developed (from the second planting). This
may have reduced competition between plants and not
reflect as intense of stress as would be expected by
the stand counts. This problem may have been compounded
as plant density increased, since there was a higher
percentage of replanted plants per treatment at high
densities as compared with the lower plant densities.

The replanting problem may account for some of the differ-
ences observed in this study as compared with previous
plant density studies.

Yield

Grain yield increased linearly with plant density
at all populations tested in this study, even at the high-
est density used, (148,260 pph). This differs from most
of the previous research on plant density (1,4,6,9,10,12,
22,26,48), where grain yield has been shown to increase
as plant density increased until a maximum yield was
obtained, (approximately 60,000 pph). Yield-density
has been shown to be a curvilinear response (42).

The row width selected and used in this study
may have influenced yield. Experiments conducted in
this report used a narrow row width (71 cm). Studies
by Eik and Hanway (9,10) were done with a 102 cm row
width. Hoff and Mederski (17) reported a yield advant-
age of more equi-distant planting compared with 107 cm
row widths, and that this yield advantage increased
as plant density increased from 50,000 to 60,000 pph.

Previous work has shown that hybrid performance
can be related to LAI (9,10). In the present experi-
ment LAI was linearly correlated with plant density
and with grain yield, however there appeared to be no
optimum LAI for grain yield. The measured LAI in this

study was lower than the reported LAI at these densities when used in other studies (9,10,29). The LAI at the highest plant density corresponded with the LAI reported by Eik and Hanway (9,10) at approximately 50,000 pph.

Yields of stover and corn silage were highly correlated with plant density. Increased plant density increased both stover and silage yields linearly. This supports data reported by Whittaker et al. (47), where stover yield and total dry matter (stover and grain) were highly correlated with plant density. They reported a positive linear relationship between yield and increased plant density, with a maximum density of 69,000 pph.

Potassium fertilization did not affect corn grain yield. This corroborates Hanway et al.'s data and conclusion that no yield increase would be expected when potassium content of the corn leaves is slightly above 2% (14). The lower potassium treatment used resulted in a leaf potassium content of 2.64% and the additional potassium applied resulted in a leaf potassium content of 2.90%. Although several workers (15,38) have reported higher grain yield at high plant densities due to increased uptake of potassium per plant at the high plant densities as compared with the lower plant densities, there was no evidence of this in this study.

Plant density has been reported to affect corn grain yield in a study by Wilson and Allison (48), where the number of kernels per ear, length and circumference of the rachis, and ear weight were considerably reduced in high corn plant densities as compared with lower plant densities. Wilson and Allison (48) also reported that florets at the tip of the ear do not produce kernels due to delayed silk emergence.

Neither plant density nor potassium had any significant effect on ear diameter or the number of kernels per ear in this study. Plant density did significantly reduce the ear weight, ear length, and the number of ears per 10 plants, which supports the data of Wilson and Allison (48). Potassium had no effect on ear weight, length or number. Silking delay, probably due to high plant density was observed, but did not seem to have any effect on the kernel development on the tip of the ear. This differs from a report by Peaslee et al. (21), where increased corn grain yields were reported due to the effect of potassium on silk emergence.

In the present study silk emergence was delayed, probably due to high plant density, however it was impossible to determine if the delayed emergence had any effect on ear. fill since two separate plantings of corn seed had to be made due to poor germination. Silk emergence was observed on the primary planting used for

all measurements. However, the corn which had been re-
seeded later, did silk later than those used for measure-
ments. The late emerging silks on the ear tips may have
been pollinated and fertilized by pollen from the reseeded
plants.

Decreased individual plant grain yields were ob-
served in the high plant densities as compared with the
lower densities of this study and a linear trend was
indicated. Unfortunately grain yields measured in this
study, especially at high densities are probably higher
than expected due to decreased competition stress from
the replanted corn. Poneleit and Egli (25) also re-
ported a significant trend of decreased plant grain
yield due to high density and they suggested that the
smaller kernels and reduced kernel number may be due
to a shorter EFPD at high corn plant densities as com-
pared with lower corn plant densities.

Silk emergence appeared to have a significant
effect on absolute growth rate of the ear at the high
plant densities used in this study. This appears to
support the data of Wilson and Allison (48), where there
was a lower absolute growth rate at high plant densities
as compared with lower corn plant densities, and this
lower growth rate resulted in kernel size reductions.
Wilson and Allison (48) suggested that an increase in
competition for assimilate between the ear and the rest

of the plant may effect the absolute growth rate.

Leaf Area/Leaf Area Index

Leaf area index (LAI) has been used as an index of potential plant interception of radiant energy. It has been suggested that LAI may be used as an indicator of hybrid performance. Research has shown that a LAI of about 3.5 seems to be optimum over a wide range of hybrids and environmental conditions (22).

Leaf area index was positively correlated with plant density in this study and increased linearly to 3.76 at 148,260 pph, the highest plant density used. The high correlation of plant density with LAI has also been reported by Eik and Hanway (9,10).

Leaf area index was also linearly correlated with grain yield. A maximum grain yield/LAI ratio was not reached. The positive correlation of grain yield and LAI is similar to some data reported by Eik and Hanway (9,10), and Nunez and Kamprath (29), however these worker reported a maximum LAI, above which yield does not increase linearly with LAI. The typical asymptotic curves of yield-density-LAI were not observed in the present study, where grain yield increased linearly with both LAI and density.

Evidence suggests that three factors, hybrid, row width, and replanting may have affected the grain

yield-LAI-density response in the present study. The
hybrid used (Wisc 335A), had smaller leaf area than the
leaf area reported by both Eik and Hanway (9,10) and
Nunez and Kamprath (29), although within the range re-
ported by Hicks and Stucker (16). Leaf orientation also
may have been different with this hybrid, and may have
caused differences in the LAI-yield responses, although
this factor was not studied in this research or by Eik
and Hanway (9,10).

Row width has been shown to affect corn grain
yield. Yao and Shaw (50) have shown that narrow row
widths apparently provide greater light interception
which results in higher yields. According to Denmead
and Shaw (5) the net radiation available for photo-
synthesis would be 15 to 20% higher in more equidistant
plantings as compared with 102 cm rows.

However, the most significant influence on LAI
in the present study was probably the replanting. This
would have caused less of a density stress than expected
from the stand counts. In addition, although the LAI
was less than expected at various densities, this may
not be an accurate gauge of LAI since many of the
plants in the canopy, especially at high densities,
were at a different developmental stage than the plants
used for LAI measurements.

Higher potassium levels decreased LAI signi-

ficantly. This may have been due to a significant increase in the K/Mg ratio from 13.25 to 16.43. The change in the K/Mg ratio was primarily due to an increase in percent potassium in the leaf tissue, although a trend toward lower magnesium uptake with higher potassium fertilization was indicated. Moss and Peaslee (28) have shown that critical levels of potassium (1.5%) and magnesium (0.15%) are associated with stomatal opening and photosynthesis. Whethether it is the ratio of K/Mg, the individual levels of potassium and magnesium, or some other re-lationship between potassium and potassium-magnesium ratios and cell growth and development is unknown.

Leaf area increased slightly as plant density increased from 49,420 pph to 98,840 pph, but this trend was not significant. Leaf area decreased at the high-est population used (148,260 pph) as compared with the lower plant densities. This leaf area reduction at high plant density appears to support data of Eik and Hanway (9,10) and Nunez and Kamprath (29), who reported a symptotic response of leaf area to plant density.

Nutrient Analyses

Increased potassium fertilization significantly increased the percent potassium in the ear leaf at silking. Calcium uptake was significantly reduced by addition of potassium. Calcium in the ear leaf tissue

was decreased from 2.55%, with 90 kg potassium per hectare, to 2.26% with 180 kg potassium per hectare. The corresponding K/Ca ratio was increased due to the higher concentration of potassium and to the decreased concentration of calcium in the leaf tissue. Stanford et al. (41) have reported similar effects of potassium fertilization on calcium uptake.

Magnesium uptake was reduced with additions of potassium fertilizer, but the trend was not significant. The K/Mg ratio and the Ca+Mg/K ratio were increased and decreased respectively, due to the increased leaf potassium concentration, decreased calcium uptake, and the trend toward a reduced magnesium uptake. This supports data of Stanford et al. (41), where reduced magnesium uptake due to increased potassium fertilization was reported.

The additional potassium applied did not have any significant effect on nitrogen or phosphorus concentrations in the ear leaf at silking. The lack of any potassium effect on nitrogen uptake may have been due to the low soil pH, which could have negated any interaction between potassium and nitrogen absorption. Phosphorus content was low at both levels of potassium application, probably due to the soil pH.

There was no effect of plant density on potassium uptake. This supports findings of Hanway et al. (14).

Although other research has indicated that higher plant density was correlated with increased potassium uptake per plant, there was no indication of that in this study.

Moisture Content

Stover moisture content was significantly increased by additional potassium with a corresponding increase in stover dry weight. This may be due to the narrow row width used in this study, or an effect of potassium on the water balance of the plant, or by increased root growth caused by potassium fertilization. Root growth was not measured in this study, however research indicates that potassium fertilization increases root growth (14).

Moisture content was not affected by plant density. This differs from some previous work (21) where moisture stress was evident with high populations, however the results in this study do support the data of Hatfield and Ragland (15), where narrow row widths appeared to offset any moisture deficit caused by the high plant density. Yao and Shaw (50) indicated that corn grown in narrow rows use water more efficiently than corn grown in wide rows.

C H A P T E R VI

CONCLUSIONS

In conclusion, plant density was correlated with grain, stover and silage yields; and with LAI. All of these variables increased linearly as plant density was increased. Increased plant density decreased the EFPD, the grain and stover yields per plant, the ear weight, ear length and the number of ears per ten plants. Potassium fertilization decreased LAI and the percent calcium in the ear leaf at silking. Increased potassium fertilization increased the percent potassium, the potassium-calcium ratio, and the potassium-magnesium ratio in the ear leaf at silking, as well as increasing the stover and leaf moisture contents. Neither plant density nor potassium fertilization affected ear fill. Most of the data were as had been expected and appear to support other plant density studies. Although the lack of a maximum yield response and the grain yield LAI response do not appear to support data from other plant density studies, these differences probably reflect problems associated with the replanting required to establish plant densities used in this study.

It has been reported (1,6,48) that kernels

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on corn ears do not fill at the tip of the ear when the plants are grown at high population densities as compared with lower population densities. There was no evidence in the present study that plant density affected kernel fill at the ear tip.

The factors that affect kernel fill on the ear tip are still unclear. Other workers (27,28,37) have reported light interception to be the limiting environmental factor in corn grain yield. Although this factor was not examined in this study, preliminary studies (unpublished data) indicates that light penetration through the corn plant canopy at high plant densities (74,130 and 98,840 pph) was not significantly different from a lower density (48,420 pph).

Peaslee et al. (31) have examined some of the effects of potassium and phosphorus on the EFPD which may be related to kernel development on the ear tip of corn. However, extensive nutritional studies and basic translocation studies on the problem of kernel development on the ear tips of corn have not been conducted. Additional potassium fertilization had no effect on corn ears in this present study.

Some workers (5,8,35) have reported that silking delay associated with moisture stress may be correlated with decreased ear fill at high plant densities. Additional studies on moisture stress at high plant

densities, using various row widths should be conducted. The basic physiological effects of moisture stress on plant growth need to be examined further.

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