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 (Zea mays, L.)

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ACKNOWLEDGMENT

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CHAPTER I

INTRODUCTION

Total grain yield of hybrid corn, \( \textit{Zea mays}, \textit{L.} \) 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 fertilizer 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.
CHAPTER 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 biological yield is maximum. At this maximum biological yield a gain in total yield per hectare due to additional 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 development. 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 critical 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 determine 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 population. 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).
CHAPTER III
MATERIALS AND METHODS

Plant Materials

A silage corn (Zea mays, 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 fertilized 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 accommodate an additional plant density. The plantings were thinned three weeks after seeding to establish population 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$_4$NO$_3$ 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

[Diagram of a field plot design with labeled sections A, B, C, and D, and distances marked as 49 m and 10.7 m.]

KEY
- A = 48,420 pph
- B = 74,130 pph
- C = 98,840 pph
- D = 148,250 pph
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 destructive 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 \[
(\text{PLA})(\text{no. of plants/land area})
\].

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.

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

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.
CHAPTER 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.

\[ \hat{Y} = 41.07 + 0.00078(x) \]

\[ r^2 = 0.72 \]
Figure 3. The effect of LAI on grain yield of corn.

\[ Y = 59.30 + 25.82(x) \]

\[ r^2 = 0.71 \]
Figure 4. Effect of plant density on corn stover yield.

\[ \hat{Y} = 2.64 + 0.00014(x) \]

\[ r^2 = 0.94 \]
Figure 5. Effect of plant density on corn silage yield.

\[ \hat{Y} = 9.11 + 0.00026(x) \]

\[ r^2 = 0.89 \]
significant effect on ear fill, or on the number of kernels 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 significantly (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 fertilization; 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**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Density (pph)</th>
<th>Trend</th>
<th>SE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>48,420</td>
<td>74,130</td>
<td>98,840</td>
</tr>
<tr>
<td>% Fill</td>
<td>88.32</td>
<td>87.37</td>
<td>88.74</td>
</tr>
<tr>
<td>Unfilled length</td>
<td>1.81</td>
<td>1.83</td>
<td>1.73</td>
</tr>
<tr>
<td>No. kernels/row</td>
<td>33.8</td>
<td>31.4</td>
<td>32.9</td>
</tr>
<tr>
<td>Ear wt. (g)</td>
<td>155.93</td>
<td>136.99</td>
<td>144.07</td>
</tr>
<tr>
<td>Ear diam. (cm)</td>
<td>4.46</td>
<td>4.31</td>
<td>4.40</td>
</tr>
<tr>
<td>Ear length (cm)</td>
<td>17.18</td>
<td>16.26</td>
<td>16.73</td>
</tr>
<tr>
<td>No. ears/10 plants</td>
<td>10.5</td>
<td>11.1</td>
<td>9.9</td>
</tr>
<tr>
<td>No. nubbins/10 plants</td>
<td>0.6</td>
<td>1.4</td>
<td>0.3</td>
</tr>
<tr>
<td>% nubbins/10 plants</td>
<td>5.3</td>
<td>10.9</td>
<td>3.3</td>
</tr>
</tbody>
</table>
## TABLE 2

**POTASSIUM EFFECTS ON EAR FILL COMPONENTS**

<table>
<thead>
<tr>
<th>Potassium level (Kg/h)</th>
<th>% Fill</th>
<th>Unfilled length</th>
<th>No. kernels/row</th>
<th>ear wt. (g)</th>
<th>ear diam (cm)</th>
<th>ear length (cm)</th>
<th>no. ears/10 plants</th>
<th>no. nubbins/10 plants</th>
<th>% nubbins/10 plants</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>86.93</td>
<td>1.79</td>
<td>32.9</td>
<td>144.58</td>
<td>4.34</td>
<td>16.46</td>
<td>10</td>
<td>.78</td>
<td>8.1</td>
</tr>
<tr>
<td>180</td>
<td>87.18</td>
<td>1.84</td>
<td>29.8</td>
<td>135.44</td>
<td>4.36</td>
<td>16.15</td>
<td>10.43</td>
<td>.88</td>
<td>7.5</td>
</tr>
</tbody>
</table>

**Probability of Difference**

| .954 | .567 | .350 | .246 | .978 | .565 | .417 | .861 | .846 |
Figure 6. Effect of plant density of corn on LAI.

\[ \hat{Y} = -0.531 + 0.00029(x) \]
\[ r^2 = 0.99 \]
### TABLE 3

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

<table>
<thead>
<tr>
<th>Total K Applied (kg/h)</th>
<th>% K&lt;sup&gt;1&lt;/sup&gt;</th>
<th>% Ca&lt;sup&gt;1&lt;/sup&gt;</th>
<th>%K/%Ca</th>
<th>%K/%Mg</th>
<th>LAI&lt;sup&gt;2&lt;/sup&gt;</th>
<th>%Moisture&lt;sup&gt;3&lt;/sup&gt; Stover</th>
<th>Stover&lt;sup&gt;3&lt;/sup&gt; Dry Wt. (kg)</th>
<th>Leaf&lt;sup&gt;4&lt;/sup&gt; Dry Wt. (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>2.64b</td>
<td>2.55a</td>
<td>10.65b</td>
<td>13.25b</td>
<td>2.00a</td>
<td>73.83b</td>
<td>0.24a</td>
<td>14.33a</td>
</tr>
<tr>
<td>180</td>
<td>2.90a</td>
<td>2.26b</td>
<td>13.30a</td>
<td>16.43a</td>
<td>1.95b</td>
<td>75.81a</td>
<td>0.22b</td>
<td>12.84b</td>
</tr>
</tbody>
</table>

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

<sup>1</sup>Nutrient analyses of 1<sup>st</sup> ear leaf at silking.

<sup>2</sup>LAI mean of whole plant samples at silking.

<sup>3</sup>Stover moisture and dry weight of 0.91 kg fresh weight sample at harvest.

<sup>4</sup>Dry wt. of 3 ear leaves/at silking treatment.
### TABLE 4

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

<table>
<thead>
<tr>
<th>Total K applied (Kg/h)</th>
<th>Plant Density (pph)</th>
<th>74,130 leaf area $^1$ (cm²)</th>
<th>98,840</th>
<th>148,260</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>49,420</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>79.39a</td>
<td>72.13a</td>
<td>69.98b</td>
<td>69.68a</td>
<td>70.99</td>
</tr>
<tr>
<td>180</td>
<td>65.52b</td>
<td>68.79b</td>
<td>72.00a</td>
<td>65.42b</td>
<td>68.64</td>
</tr>
<tr>
<td>Mean</td>
<td>69.45</td>
<td>70.35</td>
<td>70.99</td>
<td>67.55</td>
<td>69.81</td>
</tr>
</tbody>
</table>

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), significantly 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 fertilization (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**

<table>
<thead>
<tr>
<th>Density (pph)</th>
<th>EFPD (days)</th>
<th>EFPD (as compared to lowest density)</th>
</tr>
</thead>
<tbody>
<tr>
<td>49,420</td>
<td>58</td>
<td>-</td>
</tr>
<tr>
<td>74,130</td>
<td>57</td>
<td>1</td>
</tr>
<tr>
<td>98,840</td>
<td>56</td>
<td>2</td>
</tr>
<tr>
<td>148,260</td>
<td>53</td>
<td>5</td>
</tr>
</tbody>
</table>
CHAPTER V
DISCUSSION

Neither plant density nor potassium had any significant 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 differences 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 highest 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 advantage 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 experiment 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 reseeded later, did silk later than those used for measurements. 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 observed 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 reported 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 compared 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 reported 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 photosynthesis 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. Whether it is the ratio of K/Mg, the individual levels of potassium and magnesium, or some other relationship 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 highest 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.
CHAPTER 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
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.
Literature Cited


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