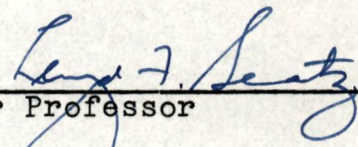


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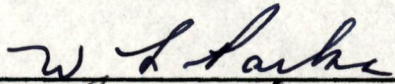
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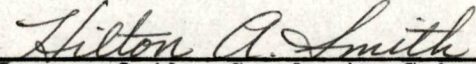
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YIELD AND CHEMICAL COMPOSITION OF CORN AND OATS GROWN AT
DIFFERENT ROOT TEMPERATURES IN SOIL AND NUTRIENT
SOLUTIONS AT DIFFERENT PHOSPHORUS LEVELS

A Thesis
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

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CHAPTER I

INTRODUCTION

The growth of plants is greatly influenced by temperatures of the environments in which they exist and are dependent upon the temperatures both above and below the soil surface. It is possible for the air temperature to be favorable for plant growth and the root-zone temperature unfavorable. The temperature effect could manifest itself in the plant by increasing or decreasing the metabolic activity of both tops and roots. For example, there may be a decrease in water uptake by the plant or there may be an accumulation of ions of one or more species over others available in the growth medium.

Numerous investigations have been concerned with the effects of temperature on plant growth. Most of these, however, have been concerned only with the overall air temperature in the fields and greenhouse with no consideration given to the effects of root temperatures. Others, working under greenhouse controlled environments have studied the temperature effects on plant growth as affected with similar temperatures of tops and roots. Relatively little work has been directed toward the specific effects of controlled root temperatures on mineral absorption.

The purpose of this investigation was to determine some of the effects of different root temperatures on the uptake of nutrient elements from both soil and nutrient solution culture while maintaining a constant air temperature.

CHAPTER II

REVIEW OF LITERATURE

Hildreth (13) reported that in its evolution the plant kingdom has become adapted to a wide range of temperatures. There are few places on earth too hot or too cold to sustain some form of plant life. Although plant protoplasm has become adapted to a wide range of temperatures, the majority of higher and lower plants are capable of carrying out growth only within a comparatively narrow range of temperatures of 0° to 50°C. Went (39) reported that average temperatures for growth of plant parts are, in general, fairly high and are usually around 25°C.

Hagen (12) suggested that although some of the effects of temperature of plant growth and development have been studied, it has been difficult to determine whether the effects are mainly on the shoot or root. According to Tisdale (35) there is considerable evidence to show that the effects of temperature on growth is largely manifested through its effect of mineral absorption. Edminster (9) stated that the absorption of solutes by roots is restricted at a low temperature which may be caused by a restricted root development. Wadleigh (36) suggested that low temperatures reduce cell membrane permeability and respiration. Millar (20) reported that the energy required for the absorption of nutrients is governed in part by metabolic activity within the

plant and not merely by the permeability of the protoplasmic membranes of the root cells. Metabolic activity in the plant roots, mobility of ions, fluidity of protoplasm, and surface phenomena must be considered when studying the relationship between nutrient absorption and soil temperature. Therefore, it is difficult to determine the effect of temperature solely on the specific processes of nutrient absorption by plants.

Richards and Wadleigh (29) stated that many investigators have reported on the relationship of climate to plant growth but they have provided only a small amount of information on the influence of soil temperature on plants.

By far the most work done with soil temperature has been done with phosphorus. Neilsen et al. (23) worked with corn and brome grass at soil temperatures of 5°, 12°, 20°, and 26°C. and found that yields of tops and roots increased with increasing temperatures to at least 20°C. They also found that with the exception of phosphorus content, composition of the crops showed few consistent trends in relation to soil temperature.

McEvoy (18) studied the effects of temperature of the medium surrounding the roots on the content of phosphorus in the tobacco plant. He found a markedly higher rate of uptake at 30°C. than at lower temperatures which indicated that the uptake of phosphorus by the tobacco crop might be reduced significantly by low soil temperatures. These results are

in agreement with Parups et al. (27) who found that, with soil temperature of 14°, 22°, and 30°C., the phosphorus content in tobacco leaf tissue decreased with decreasing temperatures.

Locascio (17) found when growing tomato plants at soil temperatures of 13°, 21°, and 30°C. that plants were more responsive to added phosphorus at the lowest temperature than at the two highest temperatures studied. He indicated that response to phosphorus was not due to a direct effect of temperature on plant growth but to the temperature effects on phosphate availability. Dadykin (5) found that the effectiveness of an application of phosphorus fertilizer was greater when barley was grown at 5° than at 17°C. He also found (4) that low temperatures reduced the speed of phosphorus fixation in the soil and thus increased its mobility.

According to Ketcheson (15) corn had a greater phosphorus uptake and yield of dry matter when the soil temperature was 20°C. than when it was 13°C. but it was shown that phosphorus fertility significantly increased the yield at each temperature level. He also suggested that the greatest uptake of phosphorus by the fertilized plants at the higher temperature appeared to result entirely in yield increases, i.e., assimilation into organic matter, whereas the greater uptake at the lower temperature appeared to result mainly in an increase in phosphorus percentage.

Apple and Butts (1) working at 17° and 28°C. suggested that the percentage of phosphorus in plant tissue may be a more reliable index of the needs of pole beans for phosphorus fertilizers than the yield response to phosphorus fertilizers. This is in disagreement with Robinson et al. (30) working with the relation of temperature and phosphate placement to growth of clover who suggested that phosphate availability is reflected in plant growth and total phosphorus uptake rather than the percentage phosphorus content of the plant.

Lingle and Davis (16) studied the influence of soil temperature and phosphorus fertilization on growth and mineral absorption of tomato seedlings at an average soil temperature of 12°, 17°, 23°, and 28°C. $\pm 1.5^\circ\text{C}$. They found that in both sand and soil culture, growth was greatest at the highest soil temperature. They also found in soil culture, response to phosphorus was greatest at the medium temperature tested while in sand culture it was greatest at the highest temperature. Their data implied that at low temperatures plants were unable to use increased phosphorus in the substrate but were able to at high temperatures.

McKell et al. (19) working with eight annual legumes at temperatures of 10°, 15.5°, and 20.1°C. found that the percentage of phosphorus in the legume species at each temperature increased as phosphorus fertility level increased. They concluded that during the cool winter weather there was an

increase in root growth for seven of the eight species. They also concluded that an increase in root growth would allow plant roots to extend into a greater volume of soil to extract moisture and nutrient supplies.

Nielsen et al. (21) observed that when oats were grown at 5°, 12.2°, 19.4°, and 26.7°C. the concentration of phosphorus in the plant increased with increasing temperatures. These trends accompanied corresponding yield increases up to 19°C.

Neilsen et al. (22) also reported a marked increase in phosphorus content of both tops and roots of lucerne as the temperature increased from 5° to 26.7°C. In all cases the lowest value for phosphorus in the tops was found at the lowest temperature. Phosphorus content of the tissue was least at the lowest phosphorus rate. The increase in yield and phosphorus content of tissue with temperature increases at the zero phosphorus rate was considered to be evidence of a greater release of phosphorus from the soil at higher temperatures.

Eid et al. (11) reported on the importance of soil organic and inorganic phosphorus to plant growth at high and low soil temperatures. They found that at 20°C., the rate of organic phosphorus mineralization was low and the plant was dependent on the inorganic fraction originally present. At 30°C. the plant was supplied with the inorganic fraction

plus additional inorganic phosphorus from mineralization of the organic fraction. Army and Miller (2) obtained similar results with a high organic soil. On Bladen soil, a marked increase in phosphorus uptake was associated with increases in soil temperatures in the range of 16° to 28°C. The organic phosphates were believed to be the main phosphorus component undergoing rapid breakdown.

Proebstring (28) grew strawberry plants at soil temperatures of 7° to 32°C. He found that the absorption of phosphorus reached a peak around 18°C. and nitrogen around 24°C.

Soil temperature and nitrogen also have an effect on the uptake of other elements. Dormaar and Ketcheson (8) found that increasing the soil temperatures from 15° to 27°C. enhanced the effect of nitrogen on phosphorus uptake by corn seedlings growing in the greenhouse. Parks and Fisher (26) reported that the calcium content of ryegrass increased with increase in soil temperatures in the range of 10°, 20°, and 30°C., and rates of nitrogen fertilization. They also found that the phosphorus uptake was directly related to the forage yield.

Ehrler and Bernstein (10) found that the lower root temperatures consistently resulted in lower levels of the major cations at maturity. However, the results were more variable when the plants were analyzed for mineral composition at the flowering stage as compared to mature plants.

The influence of soil temperature on cation uptake in barley and soybeans was studied by Wallace (37). He found that potassium, calcium, and magnesium uptake were differentially stimulated and depressed by varying soil temperature. By increasing soil temperatures, the potassium content of barley increased and then decreased and the potassium content of soybeans increased.

Davis and Lingle (7) investigated the basis of shoot response to root temperatures of 13° to 27°C. in tomato plants. They used 0.2 to 1.0 times the standard Hoagland's nutrient solution and found that each increment in nutritional level enhanced shoot growth on warm rooted plants, but not of cold rooted plants, although phosphorus and potassium concentration increased in both. They also found a weak but significant stimulation of shoot growth with plants growing in distilled water when temperature and humidity were increased. They concluded that the control of shoot growth by root temperature does not reside primarily in rates of mineral or water supply to the shoot.

Parker (25) and Tidmore (34) studying the phosphorus nutrition of corn in nutrient solutions found that maximum growth could be obtained from solution cultures containing 0.5 parts per million, as phosphorus, if large volumes of solution were used and changed frequently. Olsen (24) studying the significance of concentration on the rate of

absorption by plants in water culture found that the rates at which the individual cations or anions were absorbed from a composite nutrient solution was determined by the ratio between the concentration of these ions rather than by their absolute concentrations. Teakle (33) reported on work with wheat plants, in which the absorption of phosphorus was affected by the concentration of the soil or culture solution. However, there was no relative proportionality on absorption between the soil and culture solution.

CHAPTER III

MATERIAL AND METHODS

General

The study described herein was conducted in a growth chamber in which a controlled water bath had been installed. Both growth chamber and water bath had individual heating and cooling units.

Air temperature of the growth chamber was held at $25^{\circ}\text{C.} \pm 3^{\circ}\text{C.}$ during the light period and $25^{\circ}\text{C.} \pm 5^{\circ}\text{C.}$ over the light and dark period while the plant root zone temperature was held within $\pm 1^{\circ}\text{C.}$ for each of the three root temperatures studied.

Day length was pre-set on controlled time switches for 16 hours of light and 8 hours of darkness. Light intensity, as measured by a Weston Illumination Meter, was 1050 foot candles at one foot above the growth containers. Light was supplied by 104, 96 inch fluorescent cool white tubes plus 24 each 100 watt incandescent bulbs.

Both the corn and oat plants used in this investigation were germinated in acid washed pure silica sand. After the seedlings had reached a height of one and one-half to two inches they were removed and placed in their respective growth media.

The root temperatures used for this study were not replicated. However, the phosphorus treatments studied were replicated four times and the data collected were subjected to the analysis of variance as outlined by Cochran and Cox (3).

SOIL EXPERIMENT

Characteristics

The soil used in this experiment was a Harlsells loam which is derived from sandstone. The chemical status of this soil is of such a nature that it lends itself well for use in soil fertility investigations. It was very low in available plant nutrients and has a low pH. The cation exchange capacity was 6.75 and the exchangeable calcium, potassium, and magnesium was 1.53, 0.19, and 0.41 milliequivalents per 100 grams of oven dry soil respectively. The pH of the unlimed soil was 4.8 and was raised to a pH of 6.6 after the addition of 3 tons of lime per acre.

Preparation

Fifty-three hundred grams of air dry soil, which had been moistened to eliminate dust during preparation, was weighed into a stainless steel bucket on a Toledo balance. About one-third of this soil was placed in a large evaporating dish so that the liming materials, which included C. P. grades of $\text{Ca}(\text{OH})_2$ and MgCO_3 , could be added in a dry form and distributed uniformly throughout this portion of soil.

This soil and that remaining in the bucket was placed into a P-K Twin Shell dry blender and mixed for 15 to 20 minutes.

The soil was removed from the blender and 660 grams weighed into one-quart polyethylene freezer containers.

Fertility Treatments

Four replications of the following eight phosphorus treatments were used: 0, 50, 100, 150, 200, 250, 300, and 400 pounds P per acre. These treatments were used at each of three different root temperatures of 20°, 30°, and 40°C.

All pots received 120, 85, and 145 pounds per acre of N, K, and Mg respectively. Lime was added at the rate of three tons per acre CaCO_3 equivalent and applied as $\text{Ca}(\text{OH})_2$. The nitrogen was applied in split applications of 60 pounds at transplanting time and 60 pounds fifteen days thereafter. The N and K were added in the form of solution and were derived from C. P. grades NH_4NO_3 and K_2SO_4 chemical salts and P was added in the form of H_3PO_4 .

Moisture

Immediately after addition of the fertilizer solutions each pot was raised to twenty percent moisture content by weight and placed into the water bath to reach equilibrium at the desired root temperature. The moisture percentage was maintained by weighing the individual containers every second day during the 20° and 30°C. temperatures and adding

demineralized water to hold the moisture content at twenty percent. The 40°C. temperature pots were weighed and brought to twenty percent moisture each day since there was more evapotranspiration occurring at this temperature.

Corn (Zea mays var. Dixie 29) was the crop used in this portion of the experiment.

SOLUTION CULTURE EXPERIMENTS

Solution Characteristics

The nutrient solution used during the course of this experiment was a slight modification of Hoagland's solution used for demonstrating mineral deficiencies in plants (14). This particular solution was one lacking phosphorus. The solution was modified by replacing the recommended iron compounds by a chelated iron compound, NaFe Sequestrene containing 12 percent Fe. However, the iron content in solution remained the same as suggested by Hoagland.

Preparation of the Plant Containers

One quart Mason jars of 930 ml. capacity were used to contain the solution. These jars were painted black to exclude light. Only the bands of the two-pieced lids were used. The sealers were removed and replaced with polyethylene discs which were 1.3 mm. in thickness.

Aluminum foil was placed between the polyethylene disc and the metal cap to exclude light from the top. This

precaution was taken to prevent algae growth in the nutrient solution. Three holes were bored into the polyethylene discs with a No. 6 cork borer to subsequently support the plants and to permit insertion of the aeration tubes. This set up is shown in figure 1.

Phosphorus Treatments

Ten phosphorus treatments used during the course of this experiment were: 0, 5, 10, 15, 20, 25, 30, 40, 50, and 100 parts per million P. The solution was not replaced or replenished during the two week crop growth period. The above treatments were used at three different root temperatures of 20°, 25°, and 30°C.

The solution culture was aerated during the 16 hour day length only.

Crops Used

Two crops, corn (Zea mays var. Dixie 29), and oats (Avena sativa var. Forkeddeer) were grown at each of the three temperatures for a period of two weeks per crop. One corn seedling was placed in each of two holes described before. When oats were used, two oat seedlings were supported in each hole with pyrex glass wool. Two weeks after the plants were transplanted they were harvested, oven-dried at 70°C., and weighed. Figure 2 shows corn growing in nutrient solution prior to harvest at the 25°C. root temperature level.



Figure 1.--Apparatus used in nutrient solution study.



Figure 2.--Corn growing in nutrient solution at 25°C. root temperature.

Laboratory Analysis

The plant material was ground in a Wiley mill and a 0.20 gram sample of the tissue was analyzed for P, Ca, Mg, and K. Where the yield was less than 0.20 grams, all of the tissue from different replications were analyzed separately. The plant tissue was digested with nitric and perchloric acids. Phosphorus was determined colorimetrically by the molybdenum-blue method described by Sterges et al. (32) and the percent transmittance determined on an AC Fisher Electrophotometer. Calcium, magnesium, and potassium were determined on an aliquot of the same digestate with the Model DU Beckman flame spectrophotometer using essentially the method suggested by Shaw and Veal (31).

CHAPTER IV

RESULTS

Yield data and uptake of phosphorus, calcium, magnesium, and potassium at each root temperature for the entire study are contained in Appendices A through I.

SOIL STUDY

Dry matter yield of corn

The highest average yield of corn grown in soil at different root temperatures was at the highest level of applied phosphorus. These data are presented in Table 1.

The yields increased at each increment of added phosphorus at the 20°C. temperature and at the 30°C. temperature at all but the 250 pound rate. At the 40°C. temperature the yield was somewhat irregular relative to the different levels of added phosphorus.

At the 20°C. temperature a significant¹ increase in yield, when compared to the zero phosphorus level, was not obtained until 150 pound of phosphorus was added. At 30°C., a highly significant increase in yield was obtained with the addition of 50 pounds of phosphorus. There was no significant increase in yield at the 40°C. temperature until 250

¹"Significant" refers to differences at the 0.05 level of probability.

Table 1.--Yield of oven-dry corn grown in soil at different phosphorus and root temperature levels.

Applied phosphorus lbs./A.	Root temperature			Average
	20°C. gm.	30°C. gm.	40°C. gm.	
0	0.59 ^{a/}	0.75	0.99	0.78
50	0.85	1.68	1.36	1.30
100	1.22	2.14	1.42	1.59
150	1.34	3.15	1.37	1.95
200	1.51	3.22	1.11	1.95
250	1.79	2.88	1.60	2.09
300	2.04	3.24	1.48	2.25
400	2.97	3.66	1.95	2.86
Average	1.58	2.59	1.41	

^{a/}Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: 0.72

0.01 level: 0.95

Temperature:

0.05 level: 0.44

0.01 level: 0.58

Phosphorus x temperature:

0.05 level: 0.49

0.01 level: 0.65

pounds phosphorus per acre was applied. There was a highly significant² difference between the zero phosphorus level and the 150 pound level at the 20°C. temperature. However, a highly significant difference was noted, at the 30°C. temperature, with the addition of 100 pounds of phosphorus.

At the zero phosphorus rate the yield increased with each increase in the root temperature level although this increase was not significant. When phosphorus was applied, however, the yield tended to increase from the 20°C. to the 30°C. temperature and then decrease at the 40°C. level. The yield was highly significant at 30°C., 1.68 grams, when compared to 20°C., 0.85 grams, at the 50 pound phosphorus level. There was no significant difference in yield, at the 50 pound phosphorus level, between the 20°C. and the 40°C. temperature. When applications of 100 pounds or more of phosphorus were added, yield at the 30°C. root temperature showed a significantly higher increase than those at either the 20°C. or the 40°C. root temperature level. The yield at 40°C. was generally higher than the 20°C. temperature up to the 150 pound phosphorus level, although not significant. At this point, the yield at the 20°C. temperature was higher than that at the 40°C. level. A highly significant difference, 2.97 grams, at 20°C. and, 1.95 grams, at the 40°C. temperature was observed at the 400 pound phosphorus level.

²"Highly significant" refers to differences at the 0.01 level of probability.

When comparing the average yield over all temperature levels studied, it was observed that the yields increased with each increment of applied phosphorus. Although a yield response to the applied phosphorus was obtained the difference between each increment added was not significant. Yield at the 100 pound phosphorus level, 1.59 grams, was significantly greater than at the zero phosphorus level, 0.78 grams. There was a significant difference in yield, averaged over all temperatures, between the 50 pound and 250 pound level of added phosphorus. Addition of 300 pounds or more of phosphorus gave a highly significant yield increase when compared to the 50 pound phosphorus level. The yield of corn, averaged over all temperatures, ranged from 0.78 grams at the zero phosphorus level to 2.86 grams at the 400 pound level.

The greatest average yield for all phosphorus levels occurred at the 30°C. root temperatures, 2.59 grams. This increase over the 20°C. temperature was highly significant. The 40°C. root temperature gave the lowest average yield, 1.41 grams, and was significantly lower than the 30°C. temperature. The average yield at 20°C. was greater than at 40°C. but the difference was not significant.

These data indicate that as the soil temperatures were raised from 20°C. to 40°C. there was an increase in average yield to 30°C., over all phosphorus levels. After this temperature was reached, however, the average yield decreased.

More differences occurred among phosphorus levels at the 30°C. root temperature than at the 20°C. and 40°C. levels.

Chemical composition

The data presented are expressed as milligrams of each element per gram of oven-dry (70°C.) corn tissue and represents the average of four replications.

A summary of the phosphorus, calcium, magnesium, and potassium content of corn tissue is presented in Tables 2 through 5.

Phosphorus uptake by corn at all temperatures increased with each increment of added phosphorus and was highest at the 400 pound rate of applied phosphorus.

No significant difference in phosphorus uptake occurred, at the zero phosphorus level, between any of the root temperatures. At each phosphorus level the plant uptake at both the 20°C. and 30°C. temperatures were essentially the same. However, a significant increase in phosphorus uptake occurred at the 40°C. temperature, compared to the 20°C. and 30°C. levels at all phosphorus levels of 100 pounds or more.

When comparing the average milligrams of phosphorus absorbed per gram of plant tissue, over all temperatures, a general increase in phosphorus content was noted with increased levels of phosphorus applied to the soil. A significant increase in the average phosphorus content of corn occurred when 200 pound of phosphorus, or greater, was applied.

Table 2.--Milligrams phosphorus per gram of oven-dry corn tissue grown in soil at different phosphorus and root temperature levels.

Applied phosphorus lbs./A.	Root temperature			Average
	20°C. mg./gm.	30°C. mg./gm.	40°C. mg./gm.	
0	0.83 ^{a/}	0.80	0.58	0.74
50	0.85	0.88	0.98	0.90
100	0.88	0.88	1.48	1.08
150	0.96	0.91	1.71	1.19
200	1.18	1.00	2.12	1.43
250	1.32	1.34	2.15	1.60
300	1.33	1.35	2.51	1.73
400	1.66	1.49	3.07	2.07
Average	1.13	1.08	1.82	

^{a/}Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: 0.53

0.01 level: 0.70

Temperature:

0.05 level: 0.35

0.01 level: 0.46

Phosphorus x temperature:

0.05 level: 0.40

0.01 level: 0.53

The milligrams of phosphorus absorbed by corn at the 20°C. and 30°C. temperature were approximately the same when averaged over all phosphorus levels. When comparing the 40°C. level with the 20°C. and 30°C. temperatures a highly significant difference was observed.

Calcium in the corn tissue tended to decrease as phosphorus was applied to the soil. Calcium absorption was significantly reduced at the 20°C. and 30°C. temperatures when 50 pounds of phosphorus was applied. However, no significant difference was observed in the uptake of calcium at the 40°C. temperature except at the 250 pound rate. At each temperature level the calcium uptake was nearly the same at all phosphorus levels above the 100 pound rate. An exception to this occurred at the 20°C. temperature when 400 pounds phosphorus was applied.

Calcium uptake at the zero phosphorus level was not significantly different between the 20°C. and 30°C. temperatures. However, as the temperature was increased to 40°C. a highly significant reduction in calcium absorption occurred. When the phosphorus rates were increased from 50 pounds up to 300 pounds per acre, the uptake of calcium was significantly higher at the 20°C. temperature than at the 30°C. or 40°C. levels.

When comparing the uptake of calcium, averaged over all temperature levels, a general decrease in calcium uptake

Table 3.--Milligrams calcium per gram of oven-dry corn tissue grown in soil at different phosphorus and root temperature levels.

Applied phosphorus lbs./A.	Root temperature			Average
	20°C. mg./gm.	30°C. mg./gm.	40°C. mg./gm.	
0	15.76 ^a	16.27	9.36	13.80
50	13.65	10.18	7.98	10.60
100	12.62	9.37	8.11	10.03
150	11.12	8.41	8.31	9.28
200	10.73	8.35	8.16	9.08
250	10.83	8.99	7.38	9.07
300	11.08	8.89	8.20	9.39
400	9.22	8.09	9.07	8.79
Average	11.88	9.82	8.32	

^a/Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: 1.69

0.01 level: 2.24

Temperature:

0.05 level: 1.02

0.01 level: 1.35

Phosphorus x temperature

0.05 level: 1.60

0.01 level: 2.12

was observed. The uptake of calcium was significantly reduced when 50 pounds of phosphorus was applied. A highly significant reduction occurred when 100 pound of phosphorus was added to the soil. No significant difference in calcium uptake was observed between the 100 pound and any of the higher phosphorus levels.

Increased root temperatures showed the same general trend on the reduction of calcium in the plant tissue as did increased phosphorus levels. In this instance the highest average uptake of calcium, 11.88 milligrams, occurred at the 20°C. level and the lowest uptake, 8.32 milligrams, at the 40°C. root temperature. There was a significant reduction in the calcium content at the 30°C. level as compared to the 20°C. level and a highly significant reduction between the 40°C. and 20°C. temperatures. A significant difference occurred between the 30°C. and 40°C. temperature levels.

Magnesium uptake showed no uptake trends at the 20°C. and 30°C. temperature levels. However, at the 40°C. level the tendency was for more magnesium to be absorbed at the higher phosphorus rates. These differences were not significant at the levels of probability studied. At 20°C. the highest uptake of magnesium occurred at the 250 pound phosphorus level while at 30°C. the uptake was nearly constant at all phosphorus levels. At 40°C. the highest uptake did not occur until 400 pounds phosphorus was applied.

Table 4.--Milligrams magnesium per gram of oven-dry corn tissue grown in soil at different phosphorus and root temperature levels.

Applied phosphorus lbs./A.	Root temperature			Average
	20°C. mg.	30°C. mg.	40°C. mg.	
0	4.24 ^{a/}	3.45	2.12	3.27
50	3.76	3.33	2.00	3.03
100	4.75	3.50	2.82	3.69
150	4.40	3.05	3.00	3.48
200	4.83	3.50	2.90	3.74
250	5.59	3.37	3.00	3.99
300	4.85	3.46	3.07	3.79
400	4.75	3.36	3.25	3.79
Average	4.65	3.38	2.77	

^{a/}Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: 0.48

0.01 level: 0.63

Temperature:

0.05 level: 0.29

0.01 level: 0.38

Phosphorus x temperature:

0.05 level: N.S.

0.01 level: N.S.

A reduction in magnesium uptake occurred with each increase in root temperature at each phosphorus level. However, the uptake between temperatures at each phosphorus level was not significantly different.

When comparing the averages of magnesium absorbed, at all temperature levels, no trends were observed after the first 50 pound increment of phosphorus was applied. The lowest average uptake, 3.03 milligrams, occurred at the 50 pound phosphorus level and the highest, 3.99 milligrams, at the 250 pound level of applied phosphorus. There was however, a significant increase in the average magnesium content of the corn tissue at all phosphorus levels of 100 pounds and greater except the 150 pound rate and a highly significant increase at the 250 pound level when compared to the 50 pound phosphorus level.

When comparing averages of magnesium in the corn tissue at different root temperatures a highly significant reduction was observed with each 10°C. increase in root temperature.

Potassium absorption decreased with an increase in applied phosphorus. A significant decrease at the 50 pound rate and a highly significant reduction occurred at the 20°C. temperature with the addition of 100 pounds of phosphorus. At 30°C. and 40°C., however, a highly significant decrease in potassium uptake occurred with the first 50 pound phosphorus

Table 5.--Milligrams potassium per gram of oven-dry corn tissue grown in soil at different phosphorus and root temperature levels.

Applied phosphorus lbs./A.	Root temperature			Average
	20°C. mg./gm.	30°C. mg./gm.	40°C. mg./gm.	
0	40.34 ^{a/}	43.60	25.44	36.46
50	36.35	23.87	13.51	24.58
100	28.03	19.63	14.37	20.68
150	27.76	14.22	15.23	19.07
200	22.05	12.86	16.16	17.02
250	22.12	14.58	12.84	16.51
300	20.98	13.33	14.22	16.18
400	12.93	11.26	12.25	12.15
Average	26.32	19.17	15.50	

^{a/}Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: 5.74

0.01 level: 7.60

Temperature:

0.05 level: 3.52

0.01 level: 4.66

Phosphorus x temperature:

0.05 level: 4.94

0.01 level: 6.54

addition. Potassium uptake was highly significantly different between the 300 pound and 400 pound phosphorus levels at 20°C. There was no significant difference in the absorption of potassium at 30°C., between 150 pounds and 300 pounds phosphorus levels, and between the 50 pound and 400 pound phosphorus levels at 40°C. A significant reduction at 30°C. occurred between the 100 pound and 150 pound phosphorus levels and very little change thereafter. It should be noted that the potassium content of corn decreased almost in one-half at the 30°C. and 40°C. temperatures with the addition of 50 pounds of phosphorus. However, this did not occur at the 20°C. temperature.

There was a highly significant reduction in potassium absorption between the 20°C. and 40°C. temperatures at all except the 400 pound phosphorus rate. After 150 pounds of phosphorus was applied, there was no significant difference in the uptake of potassium between the 30°C. and 40°C. temperatures. Plants at both the 20°C. and 30°C. temperatures absorbed approximately the same amount of potassium, at the zero phosphorus level, and approximately 25.0 milligrams was absorbed at the 40°C. temperature yet uptake at the 400 pound phosphorus level was about the same at all three temperatures.

When comparing the averages of potassium, over all temperatures, absorption tended to decrease with increases in levels of applied phosphorus. Between the zero and 50 pound

phosphorus levels a highly significant reduction in potassium uptake occurred. This may be explained by the highly significant decrease, with the addition of 50 pound of phosphorus, at the 30°C. and 40°C. temperatures. There was however, a tendency for potassium uptake to decrease as phosphorus levels increased.

When comparing the average milligrams of potassium taken up by the plant at different root temperatures, the absorption was shown to be reduced with increased temperatures. A highly significant reduction occurred between the 20°C. and 30°C. levels and a significant reduction was observed between the 30°C. and 40°C. temperatures.

NUTRIENT SOLUTION STUDY

Dry matter yield of corn

Yield data for corn grown in nutrient solution are summarized in Table 6.

The 50 and 100 parts per million data were not included since the samples at one temperature had molded.

Yields of corn were not significantly different at any level of applied phosphorus or at any temperature level. There was a tendency for the yield to be higher at the 30°C. level at 25 parts per million phosphorus and greater. Generally, when phosphorus was added, the yield was greater at the 25°C. and 30°C. temperature than at 20°C.

Table 6.--Yield of oven-dry corn grown in nutrient solution at different phosphorus and root temperature levels.

Applied phosphorus ppm	Root temperature			Average
	20°C. gm.	25°C. gm.	30°C. gm.	
0	0.44 ^{a/}	0.44	0.56	0.48
5	0.56	0.88	0.79	0.74
10	0.64	0.64	0.70	0.66
15	0.54	0.97	0.77	0.76
20	0.66	0.98	0.62	0.75
25	0.44	0.77	1.02	0.74
30	0.66	0.68	0.97	0.77
40	0.21	0.49	0.77	0.49
Average	0.52	0.73	0.77	

^{a/}Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: 0.23
0.01 level: 0.30

Temperature:

0.05 level: 0.12
0.01 level: 0.16

Phosphorus x temperature

0.05 level: N.S.
0.01 level: N.S.

When comparing the average yield, over all temperature levels, a highly significant increase occurred at all levels of applied phosphorus but the 40 parts per million when compared to the zero phosphorus level. At the 40 parts per million level the yield was about the same as at the zero phosphorus level. No significant difference in yield due to added phosphorus was found between the 5 and 30 parts per million phosphorus levels.

A comparison of the yield, averaged over all phosphorus levels at different root temperatures, indicated a significant difference between the 20°C. and both the 25°C. and 30°C. temperatures. The highest average yield of 0.77 grams occurred at 30°C. but it was not significantly different from the average yield at 25°C.

Chemical composition of corn

The mineral composition data for corn grown in nutrient solution are presented in Tables 7 through 10 and are stated as milligrams uptake per gram of plant material.

A significant increase in the absorption of phosphorus at all temperatures occurred with the addition of 5 parts per million phosphorus to the nutrient solution. No significant differences were noted between the 5 and 40 parts per million phosphorus levels at 20°C. Uptake at 25°C. was significantly greater than at 20°C. from the 10 to 40 parts per million phosphorus levels. At 30°C. a

Table 7.--Milligrams phosphorus per gram of oven-dry corn tissue grown in nutrient solution at different phosphorus and root temperature levels.

Applied phosphorus ppm	Root temperature			Average
	20°C. mg./gm.	25°C. mg./gm.	30°C. mg./gm.	
0	2.04 ^{a/}	1.55	1.43	1.67
5	5.36	4.86	5.06	5.09
10	6.41	8.39	8.86	7.89
15	6.85	8.97	9.74	8.52
20	6.21	9.12	9.03	8.12
25	6.82	8.86	8.82	8.17
30	6.82	9.53	8.66	8.34
40	5.71	9.59	7.14	7.48
Average	5.06	7.61	7.34	

^{a/}Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: 1.38

0.01 level: 1.83

Temperature:

0.05 level: .86

0.01 level: 1.14

Phosphorus x temperature:

0.05 level: 1.66

0.01 level: N.S.

highly significant increase in phosphorus uptake occurred between the zero and 5 parts per million levels. A significant increase occurred between the 5 and 10 parts per million phosphorus however, after 10 parts per million phosphorus was applied the uptake of phosphorus was not significantly different.

There was no significant difference in phosphorus uptake, between temperatures, at the zero and 5 parts per million phosphorus levels. A significant difference in phosphorus absorption occurred between the 20°C. and 25°C. temperatures between 10 and 30 parts per million phosphorus levels. However, the uptake between the 25°C. and 30°C. temperature, at these levels, were similar. Phosphorus uptake at the 40 parts per million level was significantly higher at 25°C. than at the 20°C. and 30°C. temperatures.

A comparison of the average milligrams of phosphorus taken up by the plant showed a highly significant difference between the zero and 5, and 5 and 10 parts per million phosphorus levels. No significant difference in uptake was encountered between the 10 parts per million and the 40 parts per million level of applied phosphorus.

When comparing the average uptake of phosphorus by corn at different root temperatures the highest uptake was found to occur at the 25°C. temperature level. A highly significant difference was found between the average uptake

of phosphorus at the 25°C. and 30°C. root temperature levels when compared to the 20°C. level. Average uptake at 25°C. and 30°C. was about the same.

No significant difference was noted in the uptake of calcium at any level of applied phosphorus or at any root temperature level. When the temperature was increased from 20°C. to 25°C. there was a tendency for the calcium content of corn to decrease and then increase at 30°C. Some exceptions however, were noted. At the zero and 40 parts per million phosphorus levels, calcium levels were essentially the same at the 25°C. and 30°C. temperatures. At the other phosphorus levels the calcium values at 20°C. and 30°C. were similar and higher than corresponding values at 25°C.

Calcium uptake was greatest at the 20°C. temperature, intermediate at 30°C. and was much lower at 25°C. Average calcium values at each phosphorus level were not significantly different when averaged across all temperatures.

The uptake of magnesium did not follow any regular order but at 20°C. the lowest uptake occurred at 20 parts per million phosphorus and was higher at both the lower and higher phosphorus levels. At 25°C. it was lowest at 10 parts per million and at 30°C. at zero parts per million.

Magnesium tended to be absorbed at the 25°C. temperature more than at 20°C. and 30°C. when higher levels of phosphorus were used. There was a highly significant difference

Table 8.--Milligrams calcium per gram of oven-dry corn tissue grown in nutrient solution at different phosphorus and root temperature levels.

Applied phosphorus ppm	Root temperature			Average
	20°C. mg./gm.	25°C. mg./gm.	30°C. mg./gm.	
0	9.09 ^a /	7.04	7.14	7.76
5	7.86	4.09	6.46	6.14
10	8.75	5.31	7.57	7.21
15	7.59	4.64	7.27	6.50
20	7.88	4.80	7.10	6.59
25	8.64	3.77	8.63	7.01
30	9.39	3.24	7.01	6.55
40	8.10	5.10	5.92	6.37
Average	8.41	4.75	7.13	

^a/Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: N.S.

0.01 level: N.S.

Temperature:

0.05 level: 0.80

0.01 level: 1.06

Phosphorus x temperature:

0.05 level: N.S.

0.01 level: N.S.

in the uptake of magnesium at 25°C. when 25 parts per million or higher of phosphorus was added. The uptake of magnesium at 20°C. and 30°C. were similar except at the zero phosphorus level where it was higher at 20°C.. At 15 and 20 parts per million phosphorus, magnesium uptake at 30°C. exceed that at 20°C.

When comparing the uptake of magnesium, averaged over all temperatures, no significant difference was observed between levels of applied phosphorus. The highest amount taken up, 3.45 milligrams, occurred at the 40 parts per million level and the lowest, 2.16 milligrams, at the 15 parts per million level.

A comparison of the milligrams of magnesium taken up at different root temperatures, averaged over all phosphorus levels, show the greatest amount, 3.47 milligrams, was taken up at 25°C. and the lowest uptake of magnesium, 2.48 milligrams, occurred at the 30°C. level and was significantly lower than that amount taken up at the 25°C. temperature.

There was no significant difference in the uptake of potassium at any temperature or phosphorus level. The highest uptake occurred at 10 parts per million phosphorus at the 20°C. and 25°C. temperatures and 15 parts per million phosphorus at the 30°C. level. The uptake of potassium, at 20°C., was similar at the zero and 40 parts per million phosphorus levels however, at 25°C. and 30°C. the uptake at 40 parts per million exceeded that at the zero phosphorus rate.

Table 9.--Milligrams magnesium per gram of oven-dry corn tissue grown in nutrient solution at different phosphorus and root temperature levels.

Applied phosphorus ppm	Root temperature			Average
	20°C. mg./gm.	25°C. mg./gm.	30°C. mg./gm.	
0	3.41 ^a	2.91	1.96	2.76
5	2.68	3.94	2.40	3.01
10	2.65	2.00	2.43	2.36
15	1.85	2.16	2.47	2.16
20	1.82	3.52	3.06	2.80
25	2.95	4.41	2.55	3.30
30	2.73	3.79	2.47	3.00
40	2.86	5.02	2.46	3.45
Average	2.62	3.47	2.48	

^a/Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: N.S.

0.01 level: N.S.

Temperature:

0.05 level: 0.87

0.01 level: N.S.

Phosphorus x temperature

0.05 level: 0.60

0.01 level: 0.80

The uptake of potassium at the zero phosphorus level was about the same regardless of temperature. However, when phosphorus was applied there was a tendency for the uptake of potassium to be higher at the 25°C. temperature than at the 20°C. or 30°C. temperature.

When comparing the averages across all temperature levels no significant difference in uptake of potassium was found between the 5 and 25 parts per million phosphorus levels. There was a highly significant difference in uptake between all levels of applied phosphorus when compared to the zero level. An over all downward trend began at the 10 parts per million phosphorus level. However, the difference was significant only between the 10 and 30 parts per million phosphorus levels.

A comparison of potassium in the corn tissue, when averaged over all phosphorus levels, showed that uptake of potassium was highly significant at 25°C. compared to the 20°C. and the uptake at 30°C. was significantly higher than at 20°C.

Dry matter yield of oats

Dry matter yield data for oats grown in nutrient solution are summarized in Table 11.

The results for the 50 and 100 parts per million phosphorus levels were not reported since samples at the 20°C. temperature level were too small for analysis.

Table 10.--Milligrams potassium per gram of oven-dry corn grown in nutrient solution at different phosphorus and root temperature levels.

Applied phosphorus ppm	Root temperature			Average
	20°C. mg./gm.	25°C. mg./gm.	30°C. mg./gm.	
0	55.91 ^{a/}	55.45	58.04	56.47
5	69.28	81.59	74.94	75.27
10	72.03	90.00	77.86	79.96
15	67.04	89.69	78.31	78.35
20	67.58	80.51	78.06	75.38
25	62.73	80.26	76.08	73.02
30	66.06	65.58	72.99	68.31
40	54.28	83.67	71.82	69.92
Average	64.36	78.38	73.51	

^{a/}Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: 7.58

0.01 level: 10.04

Temperature:

0.05 level: 4.64

0.01 level: 6.15

Phosphorus x temperature

0.05 level: N.S.

0.01 level: N.S.

The yield of oats was similar at all temperatures at the zero phosphorus level. When phosphorus was added a highly significant increase in yield occurred at the 5 parts per million level at all temperatures. At 20°C. and 25°C. a peak was reached at the 10 parts per million phosphorus level whereas at the 30°C. temperature this peak occurred at the 5 parts per million phosphorus level. After this peak occurred the yield dropped at each successive phosphorus level until a minimum was reached at the 40 parts per million level. A significant reduction in yield of oats occurred between the 10 and 25 parts per million levels at the 20°C. and 25°C. temperature. This reduction occurred at the 15 parts per million level at 30°C.

When comparing the yield of oats over all temperature levels, a highly significant increase was observed as phosphorus was applied from the zero level, 0.16 grams, up to 5 and 10 parts per million, 0.34 grams, and then decreased.

A comparison of the average yields at different root temperatures, over all phosphorus levels, showed no significant difference at any of the temperature levels studied.

Chemical composition of oats

A summary of the chemical composition of oats grown in nutrient solution is presented in Tables 12 through 15.

The uptake of phosphorus by oats did not vary greatly after the first increment of phosphorus was added except in

Table 11.--Yield of oven-dry oats grown in nutrient solution at different phosphorus and root temperature levels.

Applied phosphorus ppm	Root temperature			Average
	20°C. gm.	25°C. gm.	30°C. gm.	
0	0.15 ^a /	0.14	0.19	0.16
5	0.33	0.25	0.42	0.33
10	0.37	0.29	0.37	0.34
15	0.30	0.22	0.24	0.25
20	0.24	0.22	0.11	0.19
25	0.12	0.19	0.10	0.14
30	0.14	0.15	0.10	0.13
40	0.07	0.14	0.08	0.09
Average	0.22	0.20	0.20	

^a/Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: 0.08

0.01 level: 0.10

Temperature:

0.05 level: N.S.

0.01 level: N.S.

Phosphorus x temperature:

0.05 level: 0.07

0.01 level: 0.09

Table 12.--Milligrams phosphorus per gram of oven-dry oat tissue grown in nutrient solution at different phosphorus and root temperature levels.

Applied phosphorus ppm	Root temperature			Average
	20°C. mg./gm.	25°C. mg./gm.	30°C. mg./gm.	
0	1.26 ^a /	1.28	1.32	1.29
5	5.61	5.00	5.10	5.24
10	5.70	5.59	5.59	5.63
15	5.80	5.41	7.08	6.10
20	8.92	5.82	6.00	6.91
25	4.83	4.53	7.00	5.45
30	4.21	4.13	7.30	5.21
40	5.57	4.28	8.62	6.16
Average	5.24	4.50	6.00	

^a/Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: 1.99

0.01 level: 2.64

Temperature:

0.05 level: 1.22

0.01 level: 1.61

Phosphorus x temperature:

0.05 level: 1.90

0.01 level: 2.52

a few instances. There was a highly significant difference in the uptake of phosphorus between the zero and 5 parts per million phosphorus levels at all temperatures. A highly significant increase occurred at the 20 parts per million phosphorus level at 20°C. No significant difference in the phosphorus content of oats was observed at the 25°C. temperature after 5 parts per million phosphorus was added. At 30°C. however, there was a tendency for the phosphorus content of oats to rise with an increase in applied phosphorus at all except the 20 parts per million phosphorus level. A peak was reached at the 20 parts per million phosphorus level at 20°C. and 25°C. however, this peak did not occur at the 30°C. temperature until 40 parts per million phosphorus was added.

There was no significant difference in the uptake of phosphorus between the 20°C. and 25°C. temperatures except the 20 parts per million level at which the uptake of phosphorus was significantly greater than either the 25°C. or 30°C. temperatures. Also, the uptake at 40 parts per million was significantly higher at 30°C. than at 20°C. There was a highly significant difference in the uptake of phosphorus at the 30°C., compared to 20°C. and 25°C., when 25 parts per million phosphorus or greater was added.

When comparing the milligrams of phosphorus taken up at different levels of applied phosphorus, averaged over all

temperatures, a highly significant difference was observed when phosphorus was added, compared to the zero level. There was no difference in the average uptake of phosphorus by the oat plant at any level of applied phosphorus.

A comparison of the milligrams of phosphorus absorbed at different root temperatures, averaged over all phosphorus levels, showed no significant difference between the 20°C. and 25°C. levels. Significant differences were observed between the 25°C. level and the 30°C. level which had values of 4.50 milligrams and 6.00 milligrams respectively.

No significant difference in the uptake of calcium with increasing phosphorus levels was observed at the 20°C. and 25°C. temperatures. At 30°C. however, a wide variation occurred with an extremely low uptake of calcium at 10 parts per million phosphorus and a very high value at the 40 parts per million level. No explanation of this occurrence can be given.

There was no significant difference in calcium uptake between temperatures up to the 20 parts per million phosphorus level. At this point, the calcium uptake at 20°C. and 25°C. was significantly lower than the 30°C. level. At 30°C. the 25 parts per million phosphorus level was significantly higher than at 25°C. however, at the 40 parts per million level the uptake of calcium was significantly higher than at either the 25°C. or 20°C. levels.

Table 13.--Milligrams calcium per gram of oven-dry oat tissue grown in nutrient solution at different phosphorus and root temperature levels.

Applied phosphorus ppm	Root temperature			Average
	20°C. mg./gm.	25°C. mg./gm.	30°C. mg./gm.	
0	10.27 ^a /	9.21	9.21	9.56
5	8.30	7.60	6.50	7.47
10	7.81	6.90	2.20	5.63
15	8.10	5.00	8.79	7.30
20	7.50	5.59	14.73	9.27
25	10.17	6.32	14.20	10.23
30	10.00	7.20	13.80	10.33
40	12.57	6.57	19.12	12.75
Average	9.34	6.80	11.07	

L.S.D. for Phosphorus:

0.05 level: N.S.

0.01 level: N.S.

Temperature:

0.05 level: 3.08

0.01 level: N.S.

Phosphorus x temperature:

0.05 level: 6.22

0.01 level: N.S.

A general downward trend was noted in the average calcium uptake to the 10 parts per million phosphorus level at which an upward shift occurred.

When comparing the milligrams of calcium absorbed, averaged over all phosphorus levels, the 30°C. root temperature was significantly higher than the 25°C. However, no difference was observed between the 20°C. and 30°C. root temperature levels.

No significant differences in the uptake of magnesium was observed at any temperature or phosphorus levels.

There was a tendency for the magnesium content to increase at 25°C. at the two highest phosphorus rates. At 20°C. and 30°C. the uptake was essentially the same at all phosphorus levels. The greatest amount of magnesium taken up at the 20°C. temperature occurred at the zero phosphorus level whereas at 25°C. the highest value was obtained at 30 parts per million phosphorus. There was not much variation in uptake of magnesium at 30°C.

When comparing the milligrams of magnesium taken up by oats averaged across all temperatures, no significant differences were observed between any phosphorus levels.

The milligrams of magnesium absorbed at different temperatures, when averaged over all phosphorus levels, was highly significant at 25°C. when compared to 30°C. and 20°C. levels. The average milligrams of magnesium absorbed

Table 14.--Milligrams magnesium per gram of oven-dry oat tissue grown in nutrient solution at different phosphorus and root temperature levels.

Applied phosphorus ppm	Root temperature			Average
	20°C. mg./gm.	25°C. mg./gm.	30°C. mg./gm.	
0	3.93 ^{a/}	8.50	4.00	5.48
5	3.70	8.40	4.00	5.34
10	3.40	8.41	4.00	5.27
15	3.70	6.59	6.00	5.43
20	3.08	7.32	6.00	5.47
25	3.50	8.00	6.00	5.83
30	3.78	13.73	6.00	7.84
40	3.57	11.93	6.00	7.17
Average	3.58	9.11	5.25	

^{a/}Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: N.S.

0.01 level: N.S.

Temperature:

0.05 level: 1.10

0.01 level: 1.46

Phosphorus x temperature:

0.05 level: N.S.

0.01 level: N.S.

were 9.11, 5.25, and 3.58 respectively. A significant increase in magnesium absorption also occurred between the 30°C. and 20°C. root temperature levels.

Potassium absorption tended to decrease at the 20°C. and 25°C. temperatures after 5 parts per million phosphorus had been added. At 30°C. the uptake decreased to 15 parts per million phosphorus and then a significant increase occurred. A highly significant decrease in potassium uptake occurred between the 15 and 25 parts per million phosphorus levels at 20°C., and between 10 and 40 parts per million level at 25°C.

There was no significant difference between temperatures with increasing levels of applied phosphorus up to 20 parts per million. After 20 parts per million phosphorus was added, there was a highly significant increase in potassium uptake at 30°C. when compared to 25°C. or 20°C. temperatures. A significant increase between the 25°C. and 20°C. level occurred at the 30 parts per million phosphorus level.

When comparing the absorption of potassium at different phosphorus levels, averaged over all temperatures, a slight, downward trend was observed when phosphorus levels increased.

A comparison of the averages of potassium absorbed, over all phosphorus levels, showed similar values at the 20°C. and 25°C. temperature levels but a highly significant increase was observed at 30°C.

Table 15.--Milligrams potassium per gram of oven-dry oat tissue grown in nutrient solution at different phosphorus and root temperature levels.

Applied phosphorus ppm	Root temperature			Average
	20°C. mg./gm.	25°C. mg./gm.	30°C. mg./gm.	
0	61.40 ^a /	61.93	62.10	61.81
5	68.09	62.08	64.90	65.02
10	63.89	61.59	63.00	62.83
15	61.40	55.18	61.08	59.22
20	56.92	56.82	71.00	61.58
25	45.83	52.21	71.00	56.35
30	44.93	54.87	70.50	56.77
40	47.10	46.07	61.50	51.56

Average

^a/Figures represent an average of four replications.

L.S.D. for Phosphorus:

0.05 level: N.S.

0.01 level: N.S.

Temperature:

0.05 level: 6.01

0.01 level: 7.97

Phosphorus x temperature:

0.05 level: 8.36

0.01 level: 11.08

CHAPTER V

DISCUSSION

Yield of corn grown in soil increased generally with each level of applied phosphorus. It was noted that the yield increased between 20°C. and 30°C. and then decreased at 40°C. At 40°C. the yield of corn was higher than at 20°C. until 150 pounds phosphorus per acre was added. Above this phosphorus level the reverse was true.

When comparing the average uptake of phosphorus at different temperature levels it was shown that the phosphorus content of corn varied directly with the amount of phosphorus applied. Similar results were reported by Weeks et al. (38). It is possible that at 20°C. the plant was not able to utilize the applied phosphorus as efficiently as it did at 30°C. This may be the reason why maximum growth was obtained at 30°C. The plant absorbed more phosphorus at 40°C. than it did at 30°C. however, the yield was lower at 40°C. It is questionable whether the decrease in growth at 40°C. was a result of the maximum growth temperature being exceeded, or alteration of the respiratory rate, thereby reducing the energy available for protein synthesis and growth processes.

The calcium, magnesium, and potassium content of corn tissue decreased with increasing rates of applied phosphorus

and increasing root temperature levels. One exception to the above statement was the magnesium content in the plant tissue did not vary greatly with increased levels of applied phosphorus. However, the calcium and magnesium relationship in tissue followed the general results of Daniel (6) who reported that grasses averaged about twice as much calcium in the plant tissue as magnesium.

An inverse relationship existed between the calcium and phosphorus content of the corn tissue. This may have been due, partially, to phosphorus combining with the calcium in the soil to form slowly soluble or insoluble calcium phosphate compounds. If this reaction occurred, then as phosphorus rates increased, less calcium would be available to the plant. This may be noted by the decidedly higher uptake of calcium at the zero phosphorus level when compared to treatments receiving phosphorus. Also, as the root temperature levels increased these compounds were probably formed faster.

It is apparent, when observing the uptake of potassium at each temperature level and the zero phosphorus levels, that with the first 50 pounds of applied phosphorus the potassium absorption decreased sharply. This decrease was more pronounced at 30°C. and 40°C. than at the 20°C. root temperature. This is in agreement with Parks and Fisher (26) who found more potassium in ryegrass at 20°C. than at the 30°C. root temperature level.

The average yield of corn grown in nutrient solution was different at any level after the first 5 parts per million of phosphorus was added to the nutrient solution except at the 40 parts per million level. However, the phosphorus content of the corn tissue did not differ greatly between the 10 and 30 parts per million phosphorus levels. The phosphorus content of the tissue increased sharply when phosphorus was added in the amount of 5 to 10 parts per million. This increase might have occurred at a somewhat lower rate of applied phosphorus as when reported by Tidmore (34). He found that when plants were grown in large containers of solution, the maximum growth of corn could be obtained with 0.5 parts per million phosphorus concentrations.

A comparison of the yield and phosphorus uptake, at different root temperatures, showed that yield and phosphorus concentration were both increased at the 25°C. and 30°C. temperature levels when compared to the 20°C. root temperature. This indicates that the corn grown at the 20°C. level would not make its maximum growth but would probably do so somewhere around the 30°C. root temperature level. Wilcox et al. (40) found that the stunting effect of low root zone temperatures on the plant could not be corrected by increasing the phosphorus concentration.

No significant difference in the uptake of calcium and magnesium occurred. However, a significant difference

was observed in potassium uptake between the zero and 5 parts per million levels after which the uptake was similar. Calcium uptake was lower at the 25°C. level than at the other temperatures studied. This may have been due partially to the greater absorption of phosphorus and magnesium at the 25°C. level which could have had a depressing effect on the uptake of calcium.

As calcium uptake decreased at 25°C. the magnesium content increased in the corn tissue. This may have been attributed ion antagonism whereby the uptake of magnesium suppressed the uptake of calcium. This is noted at each temperature studied. Calcium uptake was greater at 20°C. and 30°C. than at the 25°C. root temperature. The reverse was true for magnesium at the same temperature levels.

Potassium in the plant tissue at all phosphorus and root temperature levels was very high. This may be accounted for by the "luxury consumption" theory whereby the plant takes up more potassium than is necessary for normal growth processes. It was noted, at different temperatures, that as the calcium content of the tissue increased the potassium content decreased. Similar results were reported by Lingle and Davis (16).

There was a general increase in the yield of oats up to the 10 parts per million phosphorus level after which, with each phosphorus increment, yield decreased. The

phosphorus content of the oat tissue, accompanying this decreasing yield trend, did not change significantly. The yield of oats was not consistently influenced by the different root temperatures studied. The highest individual yield, 0.42 grams, occurred at 30°C., at the 5 parts per million phosphorus level.

The uptake of phosphorus by oats was similar at the 20°C. and 25°C. temperatures however, phosphorus absorption was higher at 30°C. than at 20°C. and 25°C. Similar results were reported by Neilsen et al. (21).

A decrease in calcium was noted when 5 parts per million phosphorus was applied. After the 20 parts per million level calcium increased at the 20°C. and 30°C. temperature but remained essentially the same at the 25°C. level.

There was no significant difference in the uptake of magnesium at different phosphorus levels although uptake at 25°C. was higher than either the 20°C. or 30°C. levels. When comparing the absorption of calcium and magnesium, at the root temperatures studied, an inverse relationship was observed. As calcium uptake decreased at 25°C. the magnesium increased in the oat tissue.

Uptake of potassium by oats was high and between the 20 and 40 parts per million phosphorus levels was greater at 30°C. than at 20°C. and 25°C.

A comparison of the corn and the oat data showed that the yield of corn grown in nutrient solution was greatest at 30°C. whereas, the yield of oats was not influenced greatly by different root temperatures. Corn yield was not materially different between the 5 and 40 parts per million phosphorus levels however, oat yield was maximum in the 5 to 10 parts per million range and decreased progressively with increases in phosphorus concentration.

The uptake of calcium by corn was lower at 25°C. than at 20°C. or 30°C. however, more magnesium was absorbed at 25°C. than at other temperatures studied. Results similar to these were obtained with oats. Although this relationship occurred it was noted that larger quantities of these elements were absorbed by oats than by corn.

The absorption of potassium by both corn and oats was very high compared to the other elements. However, the absorption of potassium by oats was not as great as that absorbed by corn. The highest uptake of potassium by corn occurred at the 25°C. root temperature whereas, oats absorbed more at 30°C.

It is hard to compare corn grown in soil with that grown in nutrient solution since their respective growth periods were different. Corn was grown in the soil for 30 days whereas it was harvested from the nutrient solution after 14 days.

Growth of corn both in soil and nutrient solution reached a maximum at the 30°C. root temperature. The greatest growth response by the plants to added phosphorus was to 400 pounds per acre for corn grown in soil, and to 30 parts per million phosphorus for corn grown in solution.

There was a regular increase in phosphorus uptake by corn as phosphorus levels were increased in the soil. The uptake of phosphorus by corn in the nutrient solution increased with the addition of 5 parts per million phosphorus to the solution but was not very different at higher phosphorus concentrations.

A reduction of calcium uptake by corn grown in soil occurred between 20°C. and 30°C. In nutrient solution the uptake of calcium was essentially the same at these temperatures and at phosphorus rates which gave maximum corn growth. As phosphorus levels were increased in the soil magnesium uptake remained about the same. As temperatures were increased from 20°C. to 30°C. a decrease in magnesium uptake occurred. Magnesium uptake by corn in nutrient solution reached a peak at the intermediate phosphorus level but uptake was essentially the same at the 20°C. and 30°C. temperatures.

Potassium tended to decrease in corn when grown in soil with an increase in phosphorus rates and an increase in temperature from 20°C. to 30°C. The reverse was generally

true for corn grown in nutrient solution. This would indicate that in soil both increase in phosphorus rates and increases in temperature had a depressing effect on potassium rates and increases in temperature had a depressing effect on potassium uptake. In nutrient solution this trend appears to be reversed.

CHAPTER VI

SUMMARY AND CONCLUSIONS

A controlled growth chamber was used to study some of the effects of different root temperatures and phosphorus levels on the yield and chemical composition of corn grown in soil and nutrient solution and of oats grown in nutrient solution.

As phosphorus levels in soil were increased both the yield and phosphorus absorption of corn increased. Calcium and potassium uptake decreased and magnesium absorption did not vary greatly in the corn plant with increasing phosphorus rates. Corn yield increased from 20°C. to 30°C. but decreased at 40°C. The uptake of phosphorus was about the same at 20°C. and 30°C. but increased at 40°C. Absorption of calcium, magnesium, and potassium all decreased as temperatures were increased.

Yield of corn grown in nutrient solution was about the same when phosphorus levels were increased except at the 40 parts per million level where a decrease was observed. Phosphorus absorption increased with the addition of 5 parts per million phosphorus to the nutrient solution, after which, the uptake was similar. No differences were observed in calcium and magnesium uptake by corn grown in nutrient solution. Potassium uptake decreased at the

higher phosphorus levels. Corn yields when grown in nutrient solution increased as temperatures increased. Uptake of phosphorus, magnesium, and potassium was higher at the 25°C. temperature than at 20°C. or 30°C. and calcium uptake was lowest at the 25°C. temperature.

Oat yields increased up to the 10 parts per million phosphorus level but at greater phosphorus concentrations, progressively decreased. The phosphorus uptake did not vary greatly after 5 parts per million of phosphorus was applied to the solution. No difference was observed in the uptake of calcium, magnesium, and potassium with increasing phosphorus levels. There was no consistent difference observed in oat yields due to temperature. The uptake of phosphorus and calcium was lower at 25°C. than at 20°C. or 30°C. and the reverse was true for magnesium absorption. Potassium uptake was about the same at 20°C. and 25°C. but increased at 30°C.

The maximum growth of corn in soil and nutrient solution occurred at 30°C., whereas oats was not consistently influenced by the different temperatures studied.

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APPENDICES

APPENDIX A

DRY MATTER YIELD OF CORN GROWN IN SOIL AT 8 PHOSPHORUS LEVELS AND UPTAKE OF PHOSPHORUS, CALCIUM, MAGNESIUM, AND POTASSIUM AT 20°C.^{1/}

Applied Phosphorus lbs./A.	Yield of dry matter in grams	Total ion uptake			Total			Uptake per gram plant material			Total Ca+Mg+K mg.
		P mg.	Ca mg.	Mg mg.	K mg.	Ca+Mg+K mg.	P mg.	Ca mg.	Mg mg.	K mg.	
0	0.592 ^{2/}	0.49	9.3	2.5	23.8	35.6	0.83	15.76	4.24	40.34	60.3
50	0.85	0.72	11.6	3.2	30.9	45.7	0.85	13.65	3.76	36.35	53.8
100	1.22	1.08	15.4	5.8	34.2	55.4	0.88	12.62	4.75	28.03	45.4
150	1.34	1.28	14.9	5.9	37.2	58.0	0.96	11.12	4.40	27.76	43.3
200	1.51	1.78	16.2	7.3	33.3	56.8	1.18	10.73	4.83	22.05	37.6
250	1.79	2.36	19.4	10.0	39.6	69.0	1.32	10.83	5.59	22.12	38.5
300	2.04	2.71	22.6	9.9	42.8	75.3	1.33	11.08	4.85	20.98	36.9
400	2.97	4.93	27.4	14.1	38.4	79.9	1.66	9.22	4.75	12.93	26.9

^{1/}Air temperature 25° ± 3°C.

^{2/}Figure represents average of four replications.

APPENDIX B

DRY MATTER YIELD OF CORN GROWN IN SOIL AT 8 PHOSPHORUS LEVELS AND UPTAKE OF PHOSPHORUS, CALCIUM, MAGNESIUM, AND POTASSIUM AT 30°C.^{1/}

Applied phosphorus lbs./A.	Yield of dry matter in grams	Total ion uptake			Total Ca+Mg+K			Uptake per gram plant material			Total Ca+Mg+K mg.
		P mg.	Ca mg.	Mg mg.	K mg.	mg.	mg.	P mg.	Ca mg.	Mg mg.	
0	0.75 ^{2/}	0.60	12.2	2.6	32.7	47.5	0.80	16.27	3.45	43.60	63.3
50	1.68	1.47	17.1	5.6	40.1	62.8	0.88	10.18	3.33	23.87	37.4
100	2.14	1.88	20.6	7.5	42.0	70.1	0.88	9.37	3.50	19.63	32.5
150	3.15	2.88	26.5	9.6	44.8	80.9	0.91	8.41	3.05	14.22	25.7
200	3.22	3.22	26.9	11.3	41.4	79.6	1.00	8.35	3.50	12.86	24.7
250	2.88	3.85	25.9	9.7	42.0	77.6	1.34	8.99	3.37	14.58	26.9
300	3.24	4.37	28.8	11.2	43.2	83.2	1.35	8.89	3.46	13.33	25.7
400	3.66	5.46	29.6	12.3	41.2	83.1	1.49	8.09	3.36	11.26	22.7

^{1/}Air temperature 25°C. $\pm$ 3°C.

^{2/}Figure represents an average of four replications.

APPENDIX C

DRY MATTER OF CORN GROWN IN SOIL AT 8 PHOSPHORUS LEVELS AND UP-
TAKE OF PHOSPHORUS, CALCIUM, MAGNESIUM, AND POTASSIUM AT 40°C. ^{1/}

Applied phosphorus lbs./A.	Yield of dry matter in grams gm.	Total					Total				
		P mg.	Ca mg.	Mg mg.	K mg.	Ca+Mg+K mg.	P mg.	Ca mg.	Mg mg.	K mg.	Ca+Mg+K mg.
0	0.992/	0.57	9.27	2.1	25.19	36.6	0.58	9.36	2.1	25.44	36.9
50	1.36	1.33	10.85	2.7	18.38	31.9	0.98	7.98	2.0	13.51	23.5
100	1.42	2.10	11.52	4.0	20.40	35.9	1.48	8.11	2.8	14.37	25.3
150	1.37	2.34	11.39	4.1	20.86	36.4	1.71	8.31	3.0	15.23	26.5
200	1.11	2.35	9.06	3.2	17.94	30.2	2.12	8.16	2.9	16.16	27.2
250	1.60	3.44	11.80	4.8	20.54	37.1	2.15	7.38	3.0	12.84	23.2
300	1.48	3.71	12.14	4.5	21.04	37.7	2.51	8.20	3.1	14.22	25.5
400	1.95	5.99	17.68	6.3	23.88	47.9	3.07	9.07	3.2	12.25	24.6

^{1/}Air temperature 25°C. $\pm$ 3°C.

^{2/}Figure represents an average of four replications.

APPENDIX D

DRY MATTER YIELD OF CORN GROWN IN NUTRIENT SOLUTION AT 10 PHOSPHORUS LEVELS AND UPTAKE OF PHOSPHORUS, CALCIUM, MAGNESIUM, AND POTASSIUM AT 20°C. ¹/₁

Applied phosphorus lbs./A.	Yield of dry matter in grams	Total ion uptake			Total			Uptake per gram plant material				Total Ca+Mg+K mg.
		P	Ca	Mg	P	Ca	Mg	P	Ca	Mg	K	
	gm.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.
0	0.442	0.9	4.0	1.5	24.6	30.1	2.04	0.09	3.41	55.9	68.4	
5	0.56	3.0	4.4	1.5	38.8	44.7	5.36	7.86	2.68	69.3	79.8	
10	0.64	4.1	5.6	1.7	46.1	53.4	6.41	8.75	2.65	72.0	83.4	
15	0.54	3.7	4.1	1.0	36.2	41.3	6.85	7.59	1.85	67.0	76.5	
20	0.66	4.1	5.2	1.2	44.6	51.0	6.21	7.88	1.82	67.6	77.3	
25	0.44	3.0	3.8	1.3	27.6	32.7	6.82	8.64	2.95	62.7	74.3	
30	0.66	4.5	6.2	1.8	43.6	51.6	6.82	9.39	2.73	66.1	78.2	
40	0.21	1.2	1.7	0.6	44.1	46.4	5.71	8.10	2.86	54.3	65.2	
50	0.12	*	*	*	*	-	*	*	*	*	*	-
100	0.11	*	*	*	*	-	*	*	*	*	*	-

¹/Air temperature 25°C. ± 3°C.

²/Figure represents an average of four replications.

*Sample too small for analysis.

APPENDIX E

DRY MATTER YIELD OF CORN GROWN IN NUTRIENT SOLUTION AT 10 PHOSPHORUS LEVELS AND UPTAKE OF PHOSPHORUS, CALCIUM, MAGNESIUM, AND POTASSIUM AT 25°C. 1

Applied phosphorus lbs./A.	Yield of dry matter in grams gm.	Total ion uptake				Total Ca+Mg+K mg.	Uptake per gram plant material				Total Ca+Mg+K mg.
		P mg.	Ca mg.	Mg mg.	K mg.		P mg.	Ca mg.	Mg mg.	K mg.	
0	0.44 <u>2</u> /	0.7	3.1	1.3	24.4	28.8	1.55	7.04	2.9	55.45	65.4
5	0.88	4.3	3.6	3.5	71.8	78.9	4.86	4.09	3.9	81.59	89.6
10	0.64	5.4	3.4	1.3	57.6	62.3	8.39	5.31	2.0	90.00	97.3
15	0.97	8.7	4.5	2.1	87.0	93.6	8.97	4.64	2.2	89.69	96.5
20	0.98	8.9	4.7	3.4	78.9	87.0	9.12	4.80	3.5	80.51	88.8
25	0.77	6.8	2.9	3.4	61.8	68.1	8.86	3.77	4.4	80.26	88.4
30	0.68	6.5	2.2	2.6	44.8	49.6	9.53	3.24	3.8	65.88	72.9
40	0.49	4.7	2.5	2.5	41.0	46.0	9.59	5.10	5.0	83.67	93.8
50	0.22	1.8	1.1	1.7	10.5	13.3	8.14	5.00	7.7	47.82	60.6
100	0.17	1.5	0.7	1.0	6.8	8.5	9.06	4.00	6.1	40.00	50.1

1/Air temperature 25°C. $\pm$ 3°C.

2/Figure represents an average of four replications.

APPENDIX F

DRY MATTER YIELD OF CORN GROWN IN NUTRIENT SOLUTION AT 10 PHOSPHORUS LEVELS
AND UPTAKE OF PHOSPHORUS, CALCIUM, MAGNESIUM, AND POTASSIUM AT 30°C. ^{1/}

Applied phosphorus lbs./A.	Yield of dry matter in grams	Total ion uptake			Total			Uptake per gram plant material			Total Ca+Mg+K mg.
		P	Ca	Mg	P	Ca	Mg	P	Ca	Mg	
	gm.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.
0	0.56 ^{2/}	0.8	4.0	1.1	32.5	37.6	1.43	7.14	1.96	58.04	67.1
5	0.79	4.0	5.1	1.9	59.2	66.2	5.06	6.46	2.40	74.94	83.8
10	0.70	6.2	5.3	1.7	54.5	61.5	8.86	7.57	2.43	77.86	87.9
15	0.77	7.5	5.6	1.9	60.3	67.8	9.74	7.27	2.47	78.31	88.0
20	0.62	5.6	4.4	1.9	48.4	54.7	9.03	7.10	3.06	78.06	88.2
25	1.02	9.0	8.8	2.6	77.6	89.0	8.82	8.63	2.55	76.08	87.3
30	0.97	8.4	6.8	2.4	70.8	80.0	8.66	7.01	2.47	72.99	82.5
40	0.77	5.5	4.6	1.9	55.3	61.8	7.14	5.92	2.46	71.82	80.2
50	0.46	3.3	2.9	1.2	28.2	32.3	7.17	6.30	2.61	61.30	70.2
100	0.27	2.5	3.3	0.5	10.9	14.7	9.26	12.22	1.85	40.37	61.4

^{1/}Air temperature 25°C. ± 3°C.

^{2/}Figure represents an average of four replications.

APPENDIX G

DRY MATTER YIELD OF OATS GROWN IN NUTRIENT SOLUTION AT 10 PHOSPHORUS LEVELS
AND UPTAKE OF PHOSPHORUS, CALCIUM, MAGNESIUM, AND POTASSIUM AT 200C.^{1/}

Applied phosphorus lbs./A.	Yield of dry matter in grams gm.	Total ion uptake			Total Ca+Mg+K mg.	Uptake per gram plant material			Total Ca+Mg+K mg.		
		P mg.	Ca mg.	Mg mg.		P mg.	Ca mg.	Mg mg.			
										K mg.	K mg.
0	0.152/	0.19	1.54	0.59	9.21	11.34	1.26	10.27	3.93	61.40	75.60
5	0.33	1.85	2.74	1.22	22.47	26.43	5.61	8.30	3.70	68.09	80.09
10	0.37	2.11	2.89	1.26	23.64	27.79	5.70	7.81	3.40	63.89	75.10
15	0.30	1.74	2.43	1.11	18.42	21.96	5.80	8.10	3.70	61.40	73.20
20	0.24	2.14	1.80	0.74	13.66	16.20	8.92	7.50	3.08	56.92	67.50
25	0.12	0.58	1.22	0.42	5.50	7.14	4.83	10.17	3.50	45.83	59.50
30	0.14	0.59	1.40	0.53	6.29	8.22	4.21	10.00	3.78	44.93	58.71
40	0.07	0.39	0.88	0.25	3.30	4.43	5.57	12.57	3.57	47.10	63.24
50	0.07	*	*	*	*	*	*	*	*	*	*
100	0.04	*	*	*	*	*	*	*	*	*	*

^{1/}Air temperature 250C. $\pm$ 30C.

^{2/}Figure represents an average of four replications.

*Sample too small for analysis.

APPENDIX H

DRY MATTER YIELD OF OATS GROWN IN NUTRIENT SOLUTION AT 10 PHOSPHORUS LEVELS
AND UPTAKE OF PHOSPHORUS, CALCIUM, MAGNESIUM, AND POTASSIUM AT 25°C.^{1/}

Applied phosphorus lbs./A.	Yield of dry matter in grams	Total ion uptake			Total			Uptake per gram plant material			Total Ca+Mg+K mg.
		P	Ca	Mg	P	Ca	Mg	P	Ca	Mg	
		mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	
0	0.14 ^{2/}	0.18	1.29	1.19	8.67	11.15	1.28	9.21	8.50	61.93	79.64
5	0.25	1.25	1.90	2.10	15.52	18.64	5.00	7.60	8.40	62.08	78.08
10	0.29	1.62	2.00	2.44	17.86	22.30	5.59	6.90	8.41	61.59	76.90
15	0.22	1.19	1.10	1.45	12.14	14.69	5.41	5.00	6.59	55.18	66.77
20	0.22	1.28	1.23	1.61	12.50	15.34	5.82	5.59	7.32	56.82	69.73
25	0.19	0.86	1.20	1.52	9.92	12.64	4.53	6.32	8.00	52.21	66.53
30	0.15	0.62	1.08	2.06	8.23	11.37	4.13	7.20	13.73	54.87	75.80
40	0.14	0.60	0.92	1.67	6.45	9.04	4.28	6.57	11.93	46.07	64.57
50	0.10	0.57	0.69	1.44	4.34	6.47	5.70	6.90	14.40	43.40	64.70
100	0.07	0.72	0.78	1.23	2.88	4.83	10.28	11.14	17.57	40.28	68.99

^{1/}Air temperature 25°C. $\pm$ 3°C.

^{2/}Figure represents an average of four replications.

APPENDIX I

DRY MATTER YIELD OF OATS GROWN IN NUTRIENT SOLUTION AT 10 PHOSPHORUS LEVELS
AND UPTAKE OF PHOSPHORUS, CALCIUM, MAGNESIUM, AND POTASSIUM AT 30°C.^{1/}

Applied phosphorus lbs./A.	Yield of dry matter in grams	Total ion uptake			Total			Uptake per gram plant material				Total Ca+Mg+K mg.
		P	Ca	Mg	P	Ca	Mg	P	Ca	Mg	K	
	gm.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	mg.	
0	0.19 ^{2/}	0.25	1.75	0.76	11.80	14.31	1.32	9.21	4.0	62.10	75.31	
5	0.42	2.14	2.73	1.68	27.26	31.67	5.10	6.50	4.0	64.90	75.40	
10	0.39	2.18	0.86	1.56	24.57	26.99	5.59	2.20	4.0	63.00	69.20	
15	0.24	1.70	2.11	1.44	14.66	18.21	7.08	8.79	6.0	61.08	75.87	
20	0.11	0.66	1.62	0.66	7.81	10.09	6.00	14.73	6.0	71.00	91.73	
25	0.10	0.70	1.42	0.60	7.10	9.12	7.00	14.20	6.0	71.00	91.20	
30	0.10	0.73	1.38	0.60	7.05	9.03	7.30	13.80	6.0	70.50	90.30	
40	0.08	0.69	1.53	0.48	4.92	6.93	8.62	19.12	6.0	61.50	86.62	
50	0.08	0.77	0.78	0.64	5.30	6.72	9.62	9.75	8.0	66.25	84.00	
100	0.05	0.61	0.08	0.35	2.49	2.92	12.20	1.60	7.0	49.80	63.60	

^{1/}Air temperature 25°C. ± 3°C.

^{2/}Figure represents an average of four replications.