THE EFFECT OF FERTILIZER PHOSPHORUS ON THE FORAGE YIELD AND THE PHOSPHORUS AND SULFATE UPTAKE OF OATS GROWN ON SALINE AND NON-SALINE SOILS

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ABSTRACT

Greenhouse experiments carried on under three environmental conditions indicated that phosphorus fertilizer increased the forage yield of oats grown on saline and non-saline soils significantly when applied at the rate of 100 pounds ammonium phosphate (11-48-0) per acre. Applications of 200 and 400 pounds ammonium phosphate per acre did not result in a further significant yield increase over the yield at the 100 pound per acre rate.

The absolute yield increase did not vary significantly between soils under any of the three environmental conditions. However, in the growth chamber the degree of response was somewhat greater on the saline soils than on the non-saline soils.

The degree of soil salinity as such did not affect the phosphorus content of the oat plants significantly. There was, however, a significant interaction between soils and fertilizer which resulted in significant differences in the phosphorus content of the plant material from the different soils. These differences, however, were more closely related to the phosphorus level of the soils than to the degree of salinity.

The sulfur content of the plant material increased with increasing degrees of salinity; this increase being especially marked in the plant material from the highly saline soil and from the growth chamber where the transpiration ratio of the plants was highest. Fertilizer phosphorus tended to decrease the level of sulfur in the plant material from the saline soils but had no significant effect on the sulfur content of the plant material from the non-saline soils. The decrease in the sulfur

content of the plant material from the highly saline soil was not statistically significant until fertilizer was applied at a rate of 400 pounds ammonium phosphate per acre.

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INTRODUCTION

Saline soils are soils which contain sufficient soluble salts in the soil solution to interfere with the growth of most plants. Such soils are commonly found in arid and semi-arid regions of the world mainly because the yearly precipitation is not sufficient to leach these salts out of the root zone. In the more humid regions these soils are found in and around imperfectly and poorly drained areas where leaching is inhibited by various factors.

The ions which most frequently accumulate in saline soils are: Na^+, Ca^{++}, Mg^{++}, Cl^-, $SO_4^=$, HCO_3^-, and NO_3^-. The ones occurring most frequently in the saline soils of Manitoba are the Ca^{++} and Mg^{++} cations and the $SO_4^=$ and Cl^- anions with the $SO_4^=$ anion being considerably more common and in higher concentrations than the Cl^- anion.

The effect of the salts on plant growth depends on the degree of salinity and on the salt tolerance of the plant species. On areas where the level of salinity is low the effect of the salts is probably not noticeable. However, as the level of salinity increases the plant growth becomes stunted and irregular, accompanied with necrosis and leaf burn.

It is generally considered that salts in the soil solution adversely affect plant growth in three different ways: (1) the high osmotic pressure of the saline soil solution reduces the plant's ability to absorb water and results in what is commonly referred to as physiological drought; (2) plants growing on saline soils frequently absorb an overabundance of salts which can be toxic to the plant growth in itself; and (3) the toxic accumulation of salts can also result in a reduced uptake of essential nutrients.

Recent work with the application of phosphate fertilizer to cereal crops growing on saline soils has shown a marked response by these crops to the fertilizer. A common explanation for this response is that the phosphate fertilizer results in a decreased concentration of harmful salts in the plant.

The purpose of this investigation, therefore, was to study the effect of phosphate fertilizer on oats when grown on soils of four different salinity levels, and to determine whether the beneficial effect of phosphate fertilizer on saline soils could be traced to a decrease in the amount of sulfur absorbed by the plant.

LITERATURE REVIEW

Butler (5) states that the uptake of salts occurs essentially in two processes: (1) the rapid entry of the salts into the apparent free space; and (2) the slower accumulation of these salts into the cell vacuoles. The first process is dependent on physical factors such as diffusion and exchange rates. The second occurs by the combination of ions with endogenously produced carrier substances.

Epstein (9) suggests that one method of cation absorption can be illustrated by the following formula:

$$\underset{\text{in soil}}{R + M} \dashrightarrow MR \dashrightarrow \underset{\text{in plant}}{M + R}$$

where M is the cation absorbed and R is the carrier substance produced by the plant. He suggests that anion accumulation may be similar and his results imply that both cations and anions are accumulated by a mechanism involving their temporary combination with a carrier substance. The affinity of these ions for the binding sites of carrier substances seemingly is governed by chemical characteristics.

Hagen and Hopkins (21) suggest that phosphorus absorption does in fact occur in a way similar to the hypothesis postulated by Butler (5). The equation they put forward is as follows:

$$R + M \underset{k_2}{\overset{k_1}{\rightleftharpoons}} MR$$

$$MR \underset{k_4}{\overset{k_3}{\rightleftharpoons}} R^1 + M$$

where R is the carrier substance and M is the phosphate ion. Apparently k_3 is the rate-limiting step of absorption. They studied the absorption of both $H_2PO_4^-$ and $HPO_4^=$ ions by excised barley roots and found that the two were absorbed through different binding sites but that absorption of both is inhibited by the OH^- ion.

Leggett and Epstein (24) studied the kinetics of sulfate absorption by barley roots and their results suggest that the absorption of the sulfate ion also involves the attachment of the ion to specific sites on carrier substances. They found that the selenate ion competes with the sulfate ion for the binding sites but that the phosphate, nitrate and chloride ions had no measurable affinity for the sulfate-selenate binding sites.

Their description of the sulfate uptake by plants is as follows:

1) sulfate ions reversibly combine with reactive sites of carriers;
2) the carrier-sulfate complex traverses a membrane not permeable to free sulfate ions;
3) sulfate ions are released internally in a rate-limiting essentially irreversible step.

This absorption process is essentially identical to that postulated by Hagen and Hopkins (21) for phosphorus and is very similar to the process of cation absorption as described by Epstein and Hagen (10).

Lundegardh (29), in reporting on the synergistic and antagonistic effects of anion absorption, points out that most cations exhibit a marked antagonistic effect upon absorbability of other cations, whereas, most anions do not. He studied the uptake of anions by calculating the deficit in the growth medium using the combinations of Cl^- and $H_2PO_4^-$, Cl^- and NO_3^-, Cl^- and $SO_4^=$, and $H_2PO_4^-$ and NO_3^- ions. Synergistic effects were noticed at low concentrations (0.005 Molar) between most tested anions and at higher concentrations the sulfate and phosphate ions had a synergistic effect upon the chloride uptake. He suggests that the antagonistic effects may be different at various concentrations and may be influenced by time because of the difference between the initial absorption and continuous accumulation. Lundegardh's results show that chlorides may suppress both nitrate and phosphate uptake but especially that of nitrate. Low concentrations of nitrate ions may stimulate chloride uptake but higher concentrations are antagonistic especially on the later period of continuous accumulation.

Bernstein and Hayward (2) report that Reifenberg and Rosovsky, using serial dilutions of saline well water containing various concentrations of added nutrients, found little or no effect of chloride ions in concentrations up to 3000 p.p.m. upon the absorption of nitrate or phosphate ions by barley seedlings. However, an increase in phosphate and nitrate concentration in the growth media did depress the chloride absorption.

Long (28) in trying to segregate the chemical and physical effects of salt on plants used approach-grafted tomato plants. By using these plants he could equalize the water tension in the tops even when the roots were in different nutrient media. By placing one set of roots of an approach-grafted tomato plant in a base nutrient medium and another in a base-nutrient medium plus added NaCl, he eliminated the osmotic pressure effect of the salt and was able to study the chemical effect of the NaCl salt. He found that the plant with its roots in the salt medium grew less vigorously than the other plant with its roots in the salt-free medium. He concluded that the tomato growth was depressed because of the accumulation of toxic quantities of NaCl. He also found that NaCl inhibited the intake of phosphate, sulfate and nitrate anions and explained the salt injury to plants as a result of two independent effects: (1) high osmotic pressures induce other physiological changes which may be detrimental to the plants; and (2) salt in the culture solution in contact with membranes of absorbing cells and/or accumulated salt within the plant may produce deleterious effects on the protoplasm itself. This could result in reduced nutrient uptake.

Eaton (7) studied the toxicity and accumulation of chloride and sulfate salts in various crops, including barley, by using different concentrations of these salts in the water supplied to the plants. He concluded that crops varied in their response to these salts and the concentrations used, but all showed toxicity symptoms when sufficient amounts of salt had accumulated in the plants.

Breazeale and McGeorge (3) studied the effect of salt concentrations on the absorption of phosphate by plants. They found the absorption of phosphorus by wheat to be only slightly reduced when grown in a medium that contained 4000 p.p.m. NaCl. Similar results were obtained when Na_2SO_4, $CaCl_2$ or $MgCl_2$ were used. They concluded that salt concentrations in amounts ordinarily found in saline soils do not materially depress absorption of phosphorus by plants. However, over long periods of time salts may accumulate and injury might develop.

Gausman and Awan (18) studied the effects of the chloride ion on the P^{32} accumulation in potatoes by adding $CaCl_2$ in varying concentrations to the soil. They found that the level of P^{32} in the leaves increased with increasing $CaCl_2$ concentrations up to 400 p.p.m. Above this level there was a progressive decrease in the amount of P^{32} taken up. In a continuation of the above study Gausman et al. (19) compared the relative effects of chloride and sulfate ions on the P^{32} uptake by potatoes and found, as before, that as the chloride concentration was increased in the substrate P^{32} uptake increased until a critical point of 300 to 450 p.p.m. of $CaCl_2$ was reached. On the other hand, the P^{32} content decreased as the sulfate concentration was increased in the substrate.

Fine and Carson (12) obtained a marked phosphate fertilizer response on barley and oats grown on moderately saline silt loam soil. The typical saline symptoms were completely alleviated when 40 or more pounds of P_2O_5 per acre were broadcasted or 20 pounds P_2O_5 per acre were applied with the seed. Soil analysis revealed a high total phosphorus content in the soil but extremely low (1 - 6 p.p.m.) NH_4F, H_2CO_3, H_2O or H_2SO_4 (.002 N) extractable phosphorus levels. This would then explain the marked growth response to fertilizer phosphorus. The authors suggested that the injury symptoms may have been due to excessive quantities of chloride and sulfate ions accumulating in the leaves. Where adequate phosphorus was supplied, the anion balance was shifted to more normal conditions and presumably less chloride and sulfate ions were absorbed.

Ferguson (11), working with wheat, obtained bigger responses to phosphate fertilizers on saline soils than on non-saline soils. He suggested that since there was no difference in the phosphorus content of the plants grown on the saline and non-saline soils that phosphorus absorption was not limited by salinity. Later, when working with barley he determined the ash content of the plant tissue and found that salt damage was related to the accumulation of salts in the plant. The rate of accumulation was reduced when the plants were adequately supplied with phosphorus and hence, the percent yield (fertilizer yield over check yield) was greater on the saline soils than on the non-saline soils.

Another possible reason for the high degree of response to phosphorus by crop grown on saline soils, as reported by Ferguson (11) and Fine and Carson (12), could be a decrease in the solubility of the soil phosphorus. A review of the literature reveals a general lack of agreement on this point. Buehrer (4) in his report on the physio-chemical relationships of soil phosphates, states that changes in the pH of the soil solution are important in determining phosphate solubility but that neutral salts also exert an important influence on phosphate solubility. However, this effect of neutral salts varies depending upon whether or not the salt contains a common ion to the slightly soluble phosphate compounds in the soil. Neutral salts, such as $CaCl_2$ and $CaSO_4$, by virtue of the common ion calcium reduce the solubility of soil phosphates, whereas, neutral salts without the common ion generally tend to increase the solubility of soil phosphates.

Starostka and Hill (37) are in agreement with Buehrer. Investigating the influence of soluble salts on the solubility of and plant response to $CaHPO_4$, they report that salts like $Ca(NO_3)_2$ decrease the solubility of the phosphate and hence, reduce the growth of alfalfa. On the other hand, magnesium, potassium and ammonium sulfates increase the solubility of $CaHPO_4$ in the laboratory and also increase the phosphorus absorption by alfalfa from $CaHPO_4$, $Ca(H_2PO_4)_2$ and $NH_4H_2PO_4$.

Lewis et al. (26) report data on phosphorus availability which are in conflict with the above-mentioned views. Working with magnesium, calcium and sodium carbonates, sulfates and chlorides, they came to the conclusion that in general increasing the rate of salts in the soil decreased the availability of both soil and fertilizer phosphorus. The calcium salts caused the greatest fixation, whereas, the sodium salts increased the availability slightly. Magnesium salts were intermediate in their effect.

Lehr and van Wesemael (25) studied the effect of a series of salts on phosphate availability in Dutch soils and came to the following conclusions. In the laboratory trials all neutral salts decreased the solubility of the soil phosphorus. The depressing effect increased in the order of the lyotropic series: Na, K, Mg, Ca. At higher concentrations of the sulfate anion the adverse effect on phosphorus solubility was less marked than that of the chloride and nitrate anion, probably because of the formation of insoluble $CaSO_4$.

METHODS AND MATERIALS

EXPERIMENT I

Characteristics of Soils Used

Saline and non-saline clay loam soils from imperfectly and moderately drained sites of the Portage Association as described by Ehrlich et al. (8) were mixed in proportions so that soil mixtures of four different salinity levels were obtained. The more pertinent characteristics of these soils are given in Table I.

The pressure plate method was used in determining the water holding capacity of the soils at one third atmosphere.

The pH determinations were made with a Radiometer pH meter #22 equipped with a glass electrode using the saturated paste method.

The inorganic carbon content of the soil was determined by decomposition of the carbonates using hydrochloric acid and absorbing the resultant CO_2 evolved in ascarite. The weight of the CO_2 evolved was converted to $CaCO_3$ and expressed as such in the table.

Available phosphorus and nitrate nitrogen were determined using the $NaHCO_3$ extraction method (33) and phenoldisulfonic acid method (40), respectively.

The level of salinity in the soils was estimated by measuring the specific conductivity of a saturated soil extract as described in the U.S.D.A. Handbook 60 (40).

The concentrations of the major cations and anions present in the saturated extract are reported in Table II. Calcium and magnesium were determined by titration with ethylenediaminetetraacetate (40). The

TABLE I

ANALYSIS OF SOILS - EXPERIMENT I

Soil No.	E. C. mmhos. per cm. @ 25°C.	% Moisture at 1/3 atmosphere pressure	pH	$CaCO_3$	$NaHCO_3$ extractable P (p.p.m.)	NO_3-N (p.p.m.)
I	1.45	42.61	7.10	.57	13.8	28.90
III	3.80	43.22	7.32	1.36	14.5	26.07
VI	6.33	44.25	7.65	2.75	11.4	10.17
X	10.43	47.75	7.90	2.77	22.0	11.59

TABLE II

ANALYSIS OF SATURATED SOIL EXTRACT - EXPERIMENT I

Soil No.	Calcium (p.p.m.)	Magnesium (p.p.m.)	Chlorides (p.p.m.)	Sulfates (p.p.m.)
I	160	144	32	330
III	512	374	16	2439
VI	480	893	-	4763
X	544	1469	1584	7828

chlorides and sulfates were precipitated and weighed as the silver and barium salts, respectively.

Fertilizer Material

A solution of $NH_4H_2PO_4$, tagged with approximately 150 uC P^{32} per gram of P^{31}, was used as the phosphate fertilizer source. The fertilizer was applied at rates equivalent to zero, 100, 200 and 400 pounds of 11-48-0 per acre. Eight replicates were used for each treatment.

General Experimental Procedures

One thousand eight hundred and twenty-five grams of dry soil were weighed into half-gallon, glazed, porcelain pots. Thirty-two pots were used for each soil, making a total of 128 pots.

At seeding time, approximately 200 grams of soil were removed from each pot and the necessary amount of fertilizer solution added. The band of fertilizer was then covered with approximately one-quarter inch of soil and twelve kernels of Rodney oats placed in pairs on the soil surface. The rest of the soil was then used to cover the oat kernels.

The soil was then brought up to field capacity by the addition of water containing the appropriate amount of NH_4NO_3 to raise the nitrate nitrogen level in each pot to that of soil I when fertilized at the 400 pound rate. This resulted in all pots having a nitrate nitrogen level of 28.5 p.p.m. and avoided bias as far as nitrate nitrogen was concerned.

To reduce surface evaporation and salt movement the pots were covered with a clear plastic after which they were randomized on a greenhouse bench. The average temperature of the greenhouse was 75°F., ranging from 65° to 92°F., and the relative humidity averaged 60% with a range of 50% to 70%.

Within a week the plants were 2 to 3 inches high. The plastic was removed, the plants thinned to leave six uniform plants in each pot. A hole for each plant was punched in the plastic which was then replaced over the pot.

To keep the moisture content of the soil at or near field capacity the plants were watered every three or four days during the first two weeks and more frequently as the transpiration rate of the plants increased. During the fifth and sixth week the plants required watering about two times every three days. The amount of water added to each pot was recorded and with the use of a check pot, covered with plastic but having no plants growing in it, the transpiration ratio of each treatment was determined.

Representative replicates of each treatment were marked two weeks after seeding and photographed at bi-weekly intervals. The growth patterns at these intervals are shown in Figures 6, 7 and 8 on pages 80, 81 and 82, respectively.

Six weeks after seeding the six plants in each pot were harvested, oven dried at 75°C. and the weight of the dry plant material recorded. The plant material was then ground to a fine powder and analysed for total and fertilizer phosphorus as well as for total sulfur content.

Analytical Methods

Plant Digestion. The plant digestion procedure outlined in the U.S.D.A. Agriculture Handbook No. 60 (40) was used to obtain a plant solution which would quantitatively retain the sulfur in the plant material. This solution was used for the determination of the sulfur content of the plant material. For the determination of total and fertilizer phosphorus the wet digestion method as described by Toth *et al*. (39) was used.

Phosphorus. Total phosphorus was determined colorimetrically using the vanadomolybdophosphoric yellow color method in a nitric acid system as outlined by Jackson (23).

The fertilizer phosphorus fraction in the plant material was determined by analysing the plant solution for P^{32} using the liquid tube method described by Veall (41).

The soil phosphorus fraction was determined by the difference between total and fertilizer phosphorus in the plant material.

Sulfur. The sulfur in the plant material was oxidized to the sulfate form during the digestion procedure and determined as $BaSO_4$ using the method described in the U.S.D.A. Agriculture Handbook No. 60 (40).

A-value. A-values were calculated using the formula suggested by Fried and Dean (14); A-value = $B\frac{(1 - y)}{y}$ where B equals the amount of fertilizer phosphorus added and y equals the fertilizer portion of the total plant phosphorus.

EXPERIMENT II

Experiment II was initiated to study the effect of phosphate fertilizer on the growth of oats when subjected to more unfavourable conditions of temperature and relative humidity. This was considered desireable in view of the extremely good growth of oats obtained under the conditions of Experiment I. In order to create conditions approximating normal field conditions a growth chamber in which the temperature and relative humidity of the air could be more accurately controlled and adjusted was used.

Characteristics of Soils Used

The soils for this experiment were prepared as described under Experiment I. The analytical methods used in characterizing the soils were the same as those used in Experiment I. The physical and chemical properties of the soils are given in Tables III and IV.

Fertilizer Material

Same as in Experiment I.

General Experimental Procedures

Experiment II was set up similar to Experiment I with some variations as mentioned above.

In Experiment II, soil X had the highest nitrate nitrogen level. When this soil was fertilized with 400 pounds of ammonium phosphate per acre it contained 29.5 p.p.m. of nitrate nitrogen. To avoid bias, the

TABLE III

ANALYSIS OF SOILS - EXPERIMENT II

Soil No.	E. C. mmhos. per cm. @ 25°C.	% Moisture at 1/3 atmosphere pressure	pH	$CaCO_3$	$NaHCO_3$ extractable P (p.p.m.)	NO_3-N (p.p.m.)
I	1.83	38.80	7.65	2.18	9.3	20.04
III	3.79	41.04	7.53	1.89	13.2	23.02
VI	6.24	42.91	7.80	3.66	9.4	24.36
X	9.64	44.73	7.75	2.32	21.1	32.98

TABLE IV

ANALYSIS OF SATURATED SOIL EXTRACT - EXPERIMENT II

Soil No.	Calcium (p.p.m.)	Magnesium (p.p.m.)	Chlorides (p.p.m.)	Sulfates (p.p.m.)
I	192	221	-	659
III	496	509	16	2604
VI	512	768	48	4746
X	528	1325	1552	7647

available nitrogen level of all treatments was brought up to this level by the addition of appropriate amounts of ammonium nitrate dissolved in the water used to bring the soils up to field capacity immediately after seeding.

After seeding the pots were placed in a greenhouse and kept there for two weeks. At that time, four pots of each treatment were removed and placed in a growth chamber. The pots in the greenhouse were watered at intervals similar to those in Experiment I but the pots in the growth chamber had to be watered every day in order to keep the soil as nearly as possible at field capacity. Check pots were kept in both the greenhouse and the growth chamber which enabled accurate transpiration ratios to be calculated.

The temperature, relative humidity and transpiration ratios of Experiments I, II(a) and II(b) are given in Table V.

Every two weeks representative replicates of the various treatments were photographed in order to keep a visual record of growth patterns. The growth patterns at the these intervals are shown in Figures 9 to 13 on pages 83 to 87, respectively.

At the end of six weeks both sets of sixty-four pots were harvested, the plant material dried at 75°C., and ground to a powder for further chemical analysis.

Analytical Methods

Plant Digestion. The plant digestion procedure outlined in the U.S.D.A. Agriculture Handbook No. 60 (40) was used to obtain a plant

TABLE V

AVERAGE TEMPERATURE, RELATIVE HUMIDITY AND TRANSPIRATION RATIO OF EXPERIMENTS I, II(a) AND II(b)

	Average temperature °F.	Average relative humidity %	Average transpiration ratio gms. H_2O/gm. dry matter
Experiment II(a) (greenhouse)	64.1	44.8	281
Experiment II(b) (growth chamber)	79.2	38.6	1061
Experiment I	75	60.0	468

solution for both the phosphorus and sulfur determinations.

Phosphorus. Same as under Experiment I.

Sulfur. Same as under Experiment I.

A-value. Same as under Experiment I.

Root Weight Determination

After harvesting the above ground portion of the oats in Experiment II, the soil in the pots from two replicates of each treatment was brought to field capacity and then placed in cold storage, at or near zero degrees Fahrenheit. The addition of water to the soil prior to freezing facilitated the removal of the soil en masse without damage to the roots. To accomplish this, the pots of frozen soil were placed upside down under a tap and hot water allowed to flow over them for about 15 seconds. This was sufficient to melt a thin layer of wet soil in contact with the pot and allowed the frozen mass to slide out of the pot without damage to the roots.

The frozen soil was placed in a wire-mesh basket. Small paper clips were fastened onto the root tops and tied to the top edge of the basket. This kept the individual root systems fairly well separated during the washing process and facilitated the removal of the soil from the roots.

The basket was then placed in a four or five gallon pail of water and allowed to stand for one to two hours. After the soil had been thawed, the basket was raised and lowered in a pump-like action till most of the soil had been removed from the roots. The roots were then removed from the basket, placed on a fine wire screen, and the remaining soil and chaff removed with the aid of a fine jet of water. The roots were then dried at 105°F. and the oven dry weight recorded.

RESULTS AND DISCUSSION

EXPERIMENT I

Dry Matter Yield

The weight of the dried plant material is recorded in Table VI. The analysis of variance (Table XX, p. 72) shows that yield differences due to fertilizer and soil treatments were significant at the one percent level. The interaction between the two treatments was not significant.

There was a significant (P = .01) difference in yield between all soils; soil I containing the lowest amount of soluble salts resulted in the highest yield and soil X containing the highest amount of soluble salts resulted in the lowest yield. Therefore, the increasing soil salinity most probably caused the decrease in yield.

One way in which salinity decreases crop yields is by increasing the total soil moisture stress. Total soil moisture stress includes the tension by which moisture is held by the soil and the osmotic pressure of the soil solution.

Veihmeyer and Hendrickson (42) are of the opinion that soil moisture is equally available over the range from the field capacity (1/3 atmospheres) to the permanent wilting point (15 atmospheres). Wadleigh (43) agrees to this concept in part when he points out that the soil moisture tension does not increase substantially until most of the available water is removed. Other investigators (1, 16, 27) maintain that plant growth does show a differential response as the soil moisture varies between field capacity and permanent wilting point.

TABLE VI

AVERAGE DRY WEIGHT OF PLANT MATERIAL - EXPERIMENT I

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
		grams			
check	4.15	3.46	2.36	2.10	3.02
100	4.54	3.84	2.72	2.49	3.40
200	4.82	4.11	2.86	2.50	3.57
400	4.61	4.15	2.84	2.39	3.50
Soil average	4.53	3.89	2.70	2.37	

Soils and fertilizer L.S.D. @ 1% = .22
@ 5% = .17

If we assume that the concept of water availability as expressed by Veihmeyer and Hendrickson and Wadleigh can be applied to this experiment then, since the soils were kept at or near field capacity, soil moisture stress should not have had a bearing on the yield results obtained.

The osmotic pressure of the soil solution, however, did vary from soil to soil. The increasing salt concentration from soil I through to soil X increased the osmotic pressure of the soil solution and also the total soil moisture stress. The saturation soil extract of soil X should have had an osmotic pressure of approximately 4 atmospheres compared to an osmotic pressure of only .5 atmospheres for the saturation soil extract of soil I (U.S.D.A. Agriculture Handbook No. 60, p. 15 (40)). As shown by Wadleigh and Ayers (44) plant growth is closely related to the total soil moisture stress and, therefore, the differences in the osmotic pressure of the soil solutions from the four different soils could be responsible for the reported differences in yield.

Soil salinity can also affect plant growth by reducing nutrient uptake or by causing a toxic concentration of soluble salts to accumulate in the plants. These effects are usually secondary in nature to the osmotic pressure effect but may have been active to some extent in reducing the yields on the saline soils of this experiment.

As mentioned earlier the differences in plant growth due to fertilizer treatments were significant at the one percent level. All fertilized treatments yielded significantly (P = .01) higher than the check treatment but there were no significant differences between the fertilized treatments at the one percent level.

The fact that the higher rates of fertilizer did not result in a significant yield increase is not surprising. Investigations carried out by Soper* revealed that crops grown on soils with available phosphorus levels below 5 p.p.m. responded to phosphate fertilizer 100 percent of the time. When grown on soils having available phosphorus levels between 5 to 12 p.p.m. they responded sixty-two percent of the time, on soils with available phosphorus levels of from 12 to 18 p.p.m. they responded fifty-six percent of the time, and on soils with available phosphorus levels above 18 p.p.m. they responded to phosphate fertilizer only twenty-nine percent of the time. One hundred pounds of ammonium phosphate per acre is equivalent to approximately 12.5 p.p.m. of phosphorus. This combined with the $NaHCO_3$ extractable soil phosphorus should be sufficient to satisfy most crop needs and hence, no further yield increase was obtained when the 200 and 400 pound rates of fertilizer were used.

The extremely good growth response of barley to phosphate fertilizer, as reported by Fine and Carson (12), was obtained on saline soils with available phosphorus levels ranging from 1.0 to 6.0 p.p.m. depending on the extractant used. Ferguson (11) obtained his results from soils having $NaHCO_3$ extractable soil phosphorus values approximately

*Unpublished data. Department of Soil Science, University of Manitoba.

equal to those used in this experiment but he used lower rates of fertilizer and expressed his results as a percentage of check yield over fertilizer yield.

The interaction between the soils and fertilizer treatments were not significant. This is contrary to the above reported results and is probably due to the relatively high $NaHCO_3$ extractable phosphorus in the soils to begin with or to the high rates of fertilizer used. There may have been a significant interaction if a series of lower fertilizer rates had been used.

The method used by Ferguson in reporting the yield response to fertilizer does not show any marked differences between soils in this experiment. The percent yield* for the soils I, III, VI and X are 91.4, 90.1, 86,8 and 84.3 respectively. Whether these differences are large enough to indicate a significantly greater response on saline soils as compared to non-saline soils is doubtful.

A-values

The A-values, as formulated by Fried and Dean (14), were calculated for the four different soils and are reported in Table VII together with the $NaHCO_3$ extractable phosphorus values. The A-values of soils I and III are approximately twice as large as the $NaHCO_3$ extractable phosphorus values. This seems to be the general trend on most normal soils. However, the A-value of soil VI is only one and a half times as large as the $NaHCO_3$ extractable phosphorus value and the two values are almost identical for soil X. Thus plants grown on the saline soils took up a

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$$*\%\ \text{yield} = \frac{\text{Yield of check}}{\text{Yield of 100 lb. rate}} \times 100$$

TABLE VII

$NaHCO_3$ EXTRACTABLE AND A-VALUE PHOSPHORUS LEVELS OF THE SOILS USED IN EXPERIMENT I

Soil No.	$NaHCO_3$ extractable phosphorus	A-value phosphorus
	mgm. per pot	mgm. per pot
I	25.20	47.3
III	26.45	53.2
VI	20.80	30.4
X	40.15	37.5

proportionally higher amount of fertilizer phosphorus than did the plants on the non-saline soils.

The absorbability of soil phosphorus is not necessarily decreased with increasing salinity even though plants growing on saline soils took up less soil phosphorus than those growing on non-saline soils. Fried and Dean (14) point out that soil phosphorus is not the only factor affecting A-values. The degree of root development also affects the A-value. This could be especially true when the fertilizer is banded. If the root development is poor the roots will feed mainly in the fertilizer band and take up proportionately less soil phosphorus. This results in lower A-values. The reverse is true when the root development is extensive.

Eaton (6) and others (20,28,45,46) have reported a decrease in the root development associated with an increase in the total soil moisture stress. This was observed to be true when some pots were dissected after harvest in Experiment II, and probably explains why the A-values were relatively lower for the saline soils than for the non-saline soils.

Phosphorus Uptake

The analysis of variance (Table XXI, p. 72) on the percent phosphorus in the plant material indicates that a significant ($P = .01$) difference existed between fertilizer treatments and between soil treatments. The interaction between the two treatments also was significant.

As shown in Table VIII, the phosphorus content of the plant material from soil I was significantly ($P = .01$) higher than from soils III, VI and X, between which there were no significant differences.

The reason for this seems to be the large increase in the phosphorus content of the plant material from soil I at the higher fertilizer rates.

According to Gausman _et_ _al_. (19) an increase in the sulfate concentrations of the substrate decreases the phosphorus content of the plants. If this is so then the increasing concentration of sulfate salts in the soil solution from soil III to soil X should decrease the amount of phosphorus the plant was able to absorb. However, as is shown in Table VIII the phosphorus content of the plants from these soils did not differ significantly indicating that the salts in general,and the sulfates in particular did not interfere with the plants' ability to absorb phosphorus.

The total amount of phosphorus absorbed by the plants decreases substantially with increasing salinity as shown in Table IX. This is probably due to the significantly lower yields with increasing salinity rather than to a decrease in the ability of the plants to absorb phosphorus.

The fact that the percent phosphorus increased significantly (P = .01) with increasing rates of phosphorus fertilizer is not surprising (Table VIII). Several authors (12, 35, 36) have reported similar results even at lower rates of phosphate fertilizer. Suffice it to point out that a significant (P = .01) increase did not occur until the 200 pound rate of ammonium phosphate had been applied. The 400 pound rate further increased the phosphorus content; again significant at the one percent level.

TABLE VIII

AVERAGE PERCENT PHOSPHORUS IN PLANT MATERIAL - EXPERIMENT I

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
check	.308	.322	.329	.303	.316
100	.314	.305	.324	.317	.315
200	.358	.327	.320	.333	.335
400	.439	.398	.362	.405	.404
Soil average	.355	.338	.337	.339	

Soils and fertilizer L.S.D. @ 1% = .010
@ 5% = .007

Soils x fertilizer L.S.D. @ 1% = .028
@ 5% = .021

TABLE IX

TOTAL PHOSPHORUS ABSORBED BY PLANTS - EXPERIMENT I

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
		mgm. of P.			
check	12.8	11.1	7.8	6.4	9.5
100	14.3	11.7	8.8	7.9	10.7
200	17.3	13.5	9.1	8.3	12.0
400	20.2	16.5	10.6	9.7	14.1
Soil average	16.1	13.1	9.1	8.0	

The interaction between soils and fertilizer treatments is shown graphically in Figure 1. The percent phosphorus in the plant material from soils I and X increased with all fertilizer rates. In the plant material from soils III and VI, there was a slight although insignificant decrease in the phosphorus content when 100 and 200 pounds per acre of ammonium phosphate was applied and only at the 400 pound rate was there a significant increase.

It is interesting to note that soil VI with the lowest $NaHCO_3$ extractable phosphorus level resulted in check plants with the highest phosphorus content and the soil X with the highest extractable phosphorus level resulted in check plants with the lowest phosphorus content. This, plus the fact that the effect of increasing rates of fertilizer upon the phosphorus content does not correlate with the level of salinity, suggests that the interaction is not due to the degree of salinity of the soil nor to the available phosphorus level, but to some other factor.

The marked increase in the phosphorus content of the plants grown on soil I with increasing amounts of fertilizer is probably the reason for the differences in percent phosphorus between soils being statistically significant. When the F-value for soils is calculated using the interaction mean square instead of the error mean square, the soil differences are not significant. In other words, the greatest factor responsible for differences in the phosphorus content of the plant material is the fertilizer and not the soil. This substantiates the hypothesis that the salinity of the soils does not affect the uptake of

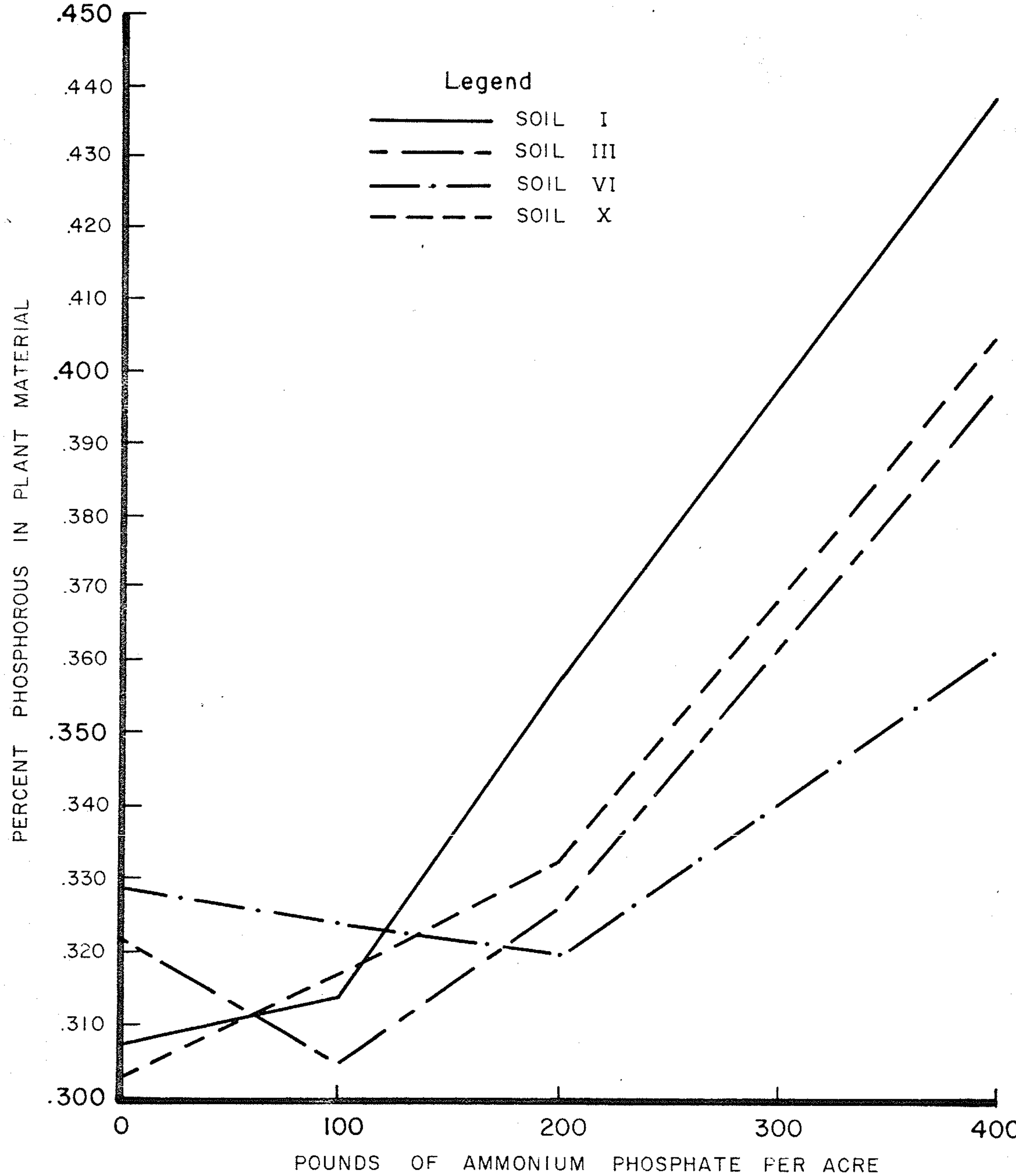

Figure 1. The Variation of the Percent Phosphorus in the Plant Material from Four Soils with Increasing Rates of Phosphorus Fertilizer - Experiment I.

phosphorus by the plant and is in agreement with results published by Breazeale and McGeorge (3), Bernstein and Hayward (2) and Ferguson (11).

Sulfur Uptake

The differences in the sulfur content of the plant material between soil treatments were significant at the one percent level but the differences between fertilizer treatments were not significant. The interaction between the soils and fertilizer treatments was significant at the five percent level (Table XXII, p. 73).

The phosphorus content of the plants from soils I, III and VI did not differ significantly at the one percent level. However, the sulfur content of the plants from soil X was significantly (P = .01) higher than that of the plants from the other soils. This seems to indicate that a soil solution can have up to approximately 5,000 p.p.m. sulfate ions (Table II, p. 11) and still not cause an increase in the sulfur content of the plants. However, somewhere above this level the sulfate absorption by plants does increase.

The average sulfur content per six plants (Table XI) was essentially the same for soils I and III but decreased substantially for soil VI; probably due to the decreased growth. However, with a further decrease in growth, such as occurred on soil X, the average sulfur content per six plants increased; this being due to the marked increase in the concentration of sulfur in the plant material.

On the average, increasing the rate of fertilizer did not decrease the sulfur content of the plant material significantly. This is substantiated by the data in Table XI. There was very little difference in the total sulfur uptake per six plants between any of the four fertilizer treatments.

On the other hand, as mentioned before, the interaction between soils and fertilizers was significant. This is shown diagramatically in Figure 2. Plants growing on soils I and III showed a slight but insignificant increase in sulfur content per gram with increasing amounts of phosphorus fertilizer. However, when grown on soils VI and X, the sulfur concentration decreased as the rate of phosphate fertilizer was increased. This decrease was not significant on soil VI but the 400 pounds per acre rate of ammonium phosphate significantly (P = .05) reduced the amount of sulfur absorbed by the plants growing on soil X.

If the concentration of sulfur in the plants from soil X was injurious, the decreased sulfur concentration resulting from the application of 400 pounds of ammonium phosphate should have resulted in a proportionately greater yield increase as compared to soils I, III or VI. This, however, was not the case (Table VI, p. 22).

The fact that phosphate fertilizer does decrease the sulfur content in some plants to some extent is in agreement with results obtained by Reifenberg and Rosovsky as reported by Bernstein and Hayward (2). It is also in agreement with data published by Ferguson (11) and if more pronounced, it would explain to a large degree the effect of the phosphorus in alleviating salinity symptoms and increasing growth as reported by Fine and Carson (12) and Ferguson (11).

TABLE X

AVERAGE SULFUR CONTENT OF PLANT MATERIAL - EXPERIMENT I
(mgm. sulfur per gm. oven dry matter)

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
check	3.80	4.34	5.31	6.93	5.09
100	4.32	4.76	4.69	5.93	4.92
200	4.24	4.77	4.50	6.24	4.94
400	4.44	5.05	4.11	5.32	4.73
Soil average	4.20	4.73	4.65	6.11	

Soils L.S.D. @ 1% = .66
@ 5% = .50

TABLE XI

TOTAL SULFUR ABSORBED BY PLANTS - EXPERIMENT I

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
		mgm. of S.			
check	15.78	15.01	12. 51	14.53	15.38
100	19.60	18.28	12.75	14.74	16.73
200	20.45	19.60	12.86	15.59	17.63
400	20.50	20.95	11.67	12.70	16.56
Soil average	19.01	18.40	12.55	14.47	

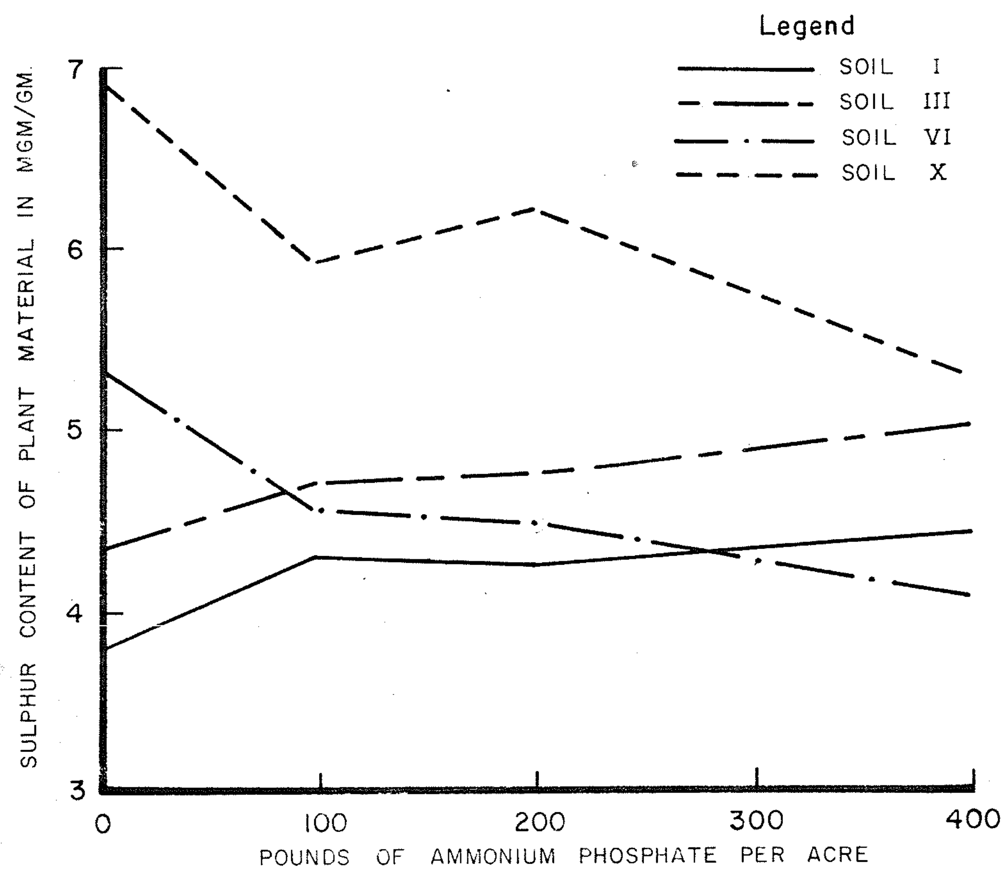

Figure 2. The Variation of the Sulfur Content in the Plant Material from Four Soils with Increasing Rates of Phosphorus Fertilizer - Experiment I.

Since the dominant salt in the saline soils was $MgSO_4$, it is highly unlikely that the salt effect on the solubility of soil phosphorus was appreciable (4, 37). The salt effect upon phosphorus absorption was not significant and the concentration of sulfur in the plant material from the saline soils apparently was not toxic enough to cause any appreciable yield reduction. Hence, the decreased moisture availability is probably the main reason for the lower yields obtained from the saline soils.

EXPERIMENT II

Dry Matter Yield

The yield data from Experiment II(a) and II(b) are given in Table XII. The analysis of variance (Table XXIII, p. 72) indicates that the soils and fertilizer effects were very similar under the two different environmental conditions. In both cases the soils and fertilizer differences were significant at the one percent level but the interactions were not significant. This is in agreement with the results reported under Experiment I.

In Experiment II(a) the yield from soil III was significantly higher (P = .01) than the yields from soils I, VI and X; also, the yield from soil I was significantly higher (P = .01) than the yields from soils VI and X. The yield difference between soils VI and X was not significant.

The yield was significantly higher from soil I than from soils VI and X which can probably be attributed to a decrease in the amount of moisture available to the plants growing in soils VI and X as discussed under Experiment I. The significantly higher yields obtained from soil III compared to that from soil I is somewhat surprising. This can most likely be attributed to the considerably higher phosphorus level in soil III as compared to soils I and VI (Table III, p. 16).

Under the conditions of Experiment II(a) the water requirement of the plants was very low (Table V, p. 18). Increasing salinity decreases the availability of soil moisture and reduces plant growth. However,

TABLE XII

AVERAGE DRY WEIGHT OF PLANT MATERIAL - EXPERIMENT II

(a) Greenhouse

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
	grams				
check	4.77	5.82	4.07	4.16	4.71
100	6.00	6.31	4.91	5.15	5.59
200	6.01	6.42	5.35	5.25	5.76
400	5.97	6.51	5.55	5.59	5.91
Soil average	5.69	6.27	4.97	5.04	

Soils and fertilizer L.S.D. @ 1% = .34
@ 5% = .26

(b) Growth Chamber

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
	grams				
check	2.50	2.52	1.57	1.31	1.98
100	2.98	2.82	1.98	1.61	2.35
200	3.09	2.69	2.10	1.80	2.42
400	2.90	3.06	2.13	2.14	2.56
Soil average	2.87	2.77	1.95	1.72	

Soils and fertilizer L.S.D. @ 1% = .22
@ 5% = .17

with the low transpiration ratios present in Experiment II(a) the decrease in moisture availability from soil VI to soil X did not affect plant growth sufficiently to result in a significantly different yield from the two soils.

In Experiment II(b) the average yields were significantly lower (P = .01) than the yields in Experiment II(a)(Table XXVI, p. 77). This probably can be attributed to the increasing salt damage with increasing transpiration ratios as suggested by Magistad _et al_. (30). The yields from soils I and III in Experiment II(b) were not significantly different but were significantly (P = .01) higher than the yields from soils VI and X. The yield from soil VI, in turn was significantly (P = .01) higher than the yield from soil X.

If salt damage actually increases with an increase in the transpiration rate as suggested by Magistad _et al_. (30) then one would have expected the yield differences between soils I and III to be greater under the environmental conditions of Experiment II(b) than under those of Experiment I. However, this was not the case. Under the conditions of the lowest transpiration ratio (Experiment II(a)), soil III yielded significantly higher than soil I (Table XII). Under the conditions of the intermediate transpiration ratio (Experiment I), soil III yielded significantly lower than soil I (Table VI, p. 22), but under the highest transpiratory conditions (Experiment II(b)), the yields from the two soils were not significantly different (Table XII). The reasons for this anomaly in Experiment II(b) are not known.

The yield differences between soils VI and X in Experiment II(b) were significant; which was also the case in Experiment I but not in Experiment II(a). This seems to indicate that at a low transpiration ratio, such as was present in Experiment II(a), the effect of salinity, as found in soils VI and X, does not differ sufficiently to affect the yield to any extent. However, at the higher transpiration ratios as found in Experiment I and Experiment II(b) these soils yielded significantly different.

The effect of the fertilizer treatments on the yield of oats was the same in both the greenhouse and the growth chamber of Experiment II and similar to that in Experiment I. The 100, 200 and 400 pound rates of fertilizer all gave a significant ($P = .01$) increase in yield over the check treatment but there were no significant ($P = .01$) yield differences between the three fertilized treatments. The $NaHCO_3$ extractable phosphorus levels of soils I and VI (Table III, p. 16) were slightly lower in Experiment II than in Experiment I, but 100 pounds of ammonium phosphate per acre was still sufficient to overcome any phosphate deficiency that may have been present in these soils.

The interactions between soils and fertilizers in both Experiment II(a) and II(b) were not significant; this was also the case in Experiment I. The absolute yield increases with additions of phosphate fertilizer were not significantly different between soils under any of the three environmental conditions.

A-values of the Soils

The A-values for the soils used in Experiment II are reported in Table XIII. It is interesting to note that the A-values were considerably higher in the greenhouse than in the growth chamber. This can be explained by examining the root weight data in Table XIV. The average root weight in Experiment II(b) was .473 grams per pot as compared to 1.482 grams in Experiment II(a). The roots in the pots from the growth chamber were considerably less extensive than those in the pots from the greenhouse and only reached the bottom of the pots under the more favourable conditions (soil I). In the greenhouse, the roots penetrated to the bottom of the pots in all soils with the exception of soil X. Therefore, the roots developing under the growth chamber conditions were in relatively closer contact with the fertilizer band and consequently, absorbed a higher proportion of fertilizer phosphorus which resulted in lower A-values.

The ratios of the A-value to $NaHCO_3$ value in Table XIII are considerably higher for soils I, III and VI than for soil X. The root development as shown in Table XIV was poorest in soil X under both environmental conditions and this fact may be used as an explanation for the above mentioned results. However, under both environmental conditions the difference in root development between soils VI and X is less than between soils III and VI and yet the A-value to $NaHCO_3$ value ratios of soil VI approximate the ratios for soil III more nearly than the ratios for soil X. Therefore, it is obvious that root development is not the only factor causing these ratios to vary. Possibly the high degree of

TABLE XIII

$NaHCO_3$ EXTRACTABLE AND A-VALUE PHOSPHORUS LEVELS OF THE SOILS USED IN EXPERIMENT II

Soil No.	$NaHCO_3$ extractable phosphorus	A-value phosphorus greenhouse	A-value phosphorus growth chamber	A-value / $NaHCO_3$ value ratios greenhouse	A-value / $NaHCO_3$ value ratios growth chamber
		mgm. per pot			
I	16.95	35.79	27.96	2.11	1.65
III	24.10	59.73	47.66	2.47	1.98
VI	17.15	40.27	30.10	2.49	1.76
X	38.50	52.03	41.27	1.35	1.07

TABLE XIV

DRY WEIGHT OF ROOTS - EXPERIMENT II
(average of two replicates)

(a) Greenhouse

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
		grams			
check	1.315	1.687	.937	1.198	1.284
100	1.793	1.820	1.149	1.075	1.459
200	1.731	2.156	1.287	1.192	1.592
400	1.887	2.084	1.327	1.090	1.597
Soil average	1.682	1.937	1.175	1.139	1.482

(b) Growth Chamber

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
		grams			
check	.573	.519	.362	.254	.427
100	.640	.570	.430	.307	.487
200	.596	.502	.409	.348	.464
400	.624	.640	.446	.353	.516
Soil average	.583	.558	.412	.316	.473

salinity of soil X does affect the availability of soil phosphorus to the plant even though this is not shown by the $NaHCO_3$ extractable values.

Phosphorus Uptake

The percent phosphorus in the plant material of Experiment II is given in Table XV. In both the greenhouse and the growth chamber the differences in the phosphorus content of the plant material due to soils and to fertilizers were significant at the one percent level. The interaction between soil and fertilizer treatments was significant at the one percent level in the greenhouse but only significant at the five percent level in the growth chamber (Table XXIV, p. 75).

In Experiment II(a), the phosphorus content of the plant material from soils I and VI was significantly ($P = .01$) lower than that of the plant material from soils III and X, but the differences between soils I and VI or soils III and X were not significant at the one percent level. These results could be due to the different phosphate levels in the soils as listed in Table III, p. 16. Soils I and VI have similar $NaHCO_3$ extractable phosphorus levels which are lower than the level in soil III, which is again lower than the level in soil X. The other, and more likely reason for the differences, is the interaction between soils and fertilizers. When no phosphorus fertilizer was applied the differences in the phosphorus content of the plant material between soils were not significant. However, when phosphorus fertilizer was applied the phosphorus content of the plant material was significantly different between soils. For example, the percent phosphorus in the plant material from

TABLE XV

AVERAGE PERCENT PHOSPHORUS IN PLANT MATERIAL - EXPERIMENT II

(a) Greenhouse

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
check	.228	.231	.256	.227	.236
100	.220	.257	.253	.257	.247
200	.251	.288	.249	.295	.271
400	.293	.318	.283	.330	.306
Soil average	.248	.274	.260	.277	

Soils and fertilizers L.S.D. @ 1% = .015
@ 5% = .011

Soils x fertilizers L.S.D. @ 1% = .042
@ 5% = .032

(b) Growth Chamber

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
check	.300	.326	.326	.295	.312
100	.299	.318	.323	.334	.318
200	.338	.340	.331	.354	.341
400	.326	.371	.343	.371	.353
Soil average	.315	.338	.330	.338	

Soils and fertilizers L.S.D. @ 1% = .018
@ 5% = .013

Soils x fertilizers L.S.D. @ 1% = .051
@ 5% = .038

soil I did not differ significantly from the check to the 100 pound treatment, and from soil VI it did not differ significantly from the check to the 100 pound and to the 200 pound treatment. However, on soils III and X there was a gradual and significant (P = .01) increase in the phosphorus level of the plant material as the fertilizer rate was increased. Hence, if the interaction mean square is used instead of the error mean square in calculating the soil F-value, the differences attributed to the soils are not significant.

The plants from the growth chamber had a significantly (P = .01) higher phosphate level than those from the greenhouse (Table XXVII, p. 78). The soil differences in the growth chamber were significant at the one percent level. The plant material from soil I was significantly (P = .01) lower in percent phosphorus than that from soils III and X and was also lower in phosphorus than that from soil VI but this was only significant at the five percent level. The percent phosphorus in the plant material from soils III, VI, and X did not differ significantly. Probably the soil differences were again due to the significant interaction. One of the reasons for the significant interaction between soil and fertilizer treatments is that on soil I the 400 pound rate of fertilizer decreased the percent phosphorus in the plant material slightly although not significantly from the level at the 200 pound rate, whereas, on all other soils this fertilizer rate increased the percent phosphorus in the plant material over that of the 200 pound rate; significantly (P = .05) on soils III and X but not significantly on soil VI. If soil I had reacted similarly to the other soils, the soil differences probably would not have been significant. Again, when the interaction mean square is used instead of the error mean square in calculating the soil F-value, the differences attributed to soils are not really significant.

The results in Table XVI show the phosphorus uptake by the greenhouse plants grown in soils I, VI and X to be very similar. Plants from soil III took up slightly more phosphorus probably because the soil initially had a higher extractable phosphorus level. Since soil X had a higher level of extractable phosphorus than soil III one would expect the plants from this soil to have absorbed the highest amount of phosphorus. However, the low total plant weight probably kept the total phosphorus in the plant material down to the level of the plants from soil I and VI.

In the growth chamber (Table XVI), there was a gradual decline in the total amount of phosphorus taken up by the plants as the salinity increased even though the percent phosphorus remained almost constant. However, the yield also decreased with salinity and this could account for the decrease in total phosphorus absorbed by the plants.

Since differences in the phosphorus concentration of the plant material due to soil differences in both the greenhouse and the growth chamber can be attributed to either a significant interaction between soils and fertilizers or to varying soil phosphorus levels, and since the plant material from the saline soils tends to be slightly higher than the non-saline soils in phosphorus content, and since the variations in total phosphorus absorbed can be attributed to differences in the yield, the conclusion that salinity has no harmful effect upon phosphorus absorption seems logical.

TABLE XVI

TOTAL PHOSPHORUS ABSORBED BY PLANTS - EXPERIMENT II

(a) Greenhouse

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
	mgm. of P.				
check	10.85	13.61	10.39	9.42	11.07
100	13.17	16.40	12.42	10.77	13.77
200	15.05	18.50	13.26	15.48	15.57
400	17.50	20.59	15.70	18.46	18.06
Soil average	14.14	17.22	12.94	14.16	

(b) Growth Chamber

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
	mgm. of P.				
check	7.51	8.25	5.11	3.84	6.18
100	8.91	8.96	6.37	5.36	7.40
200	10.42	9.11	6.89	6.33	8.19
400	9.45	11.33	7.29	7.95	9.00
Soil average	9.07	9.41	6.42	5.87	

The differences in the percent phosphorus due to fertilizer treatments were significant at the one percent level in both the greenhouse and the growth chamber (Table XXIV, p. 75). In fact, the trends under all three environmental conditions of the two experiments were almost identical (Table VIII, p. 29 and Table XV, p. 44). Under all three conditions, the check and 100 pound treatments were not significantly different. The w00 pound rate resulted in significantly (P = .01) higher percent phosphorus values than the check or 100 pound treatments under all three conditions. However, the 400 pound rate only gave a significant (P = .01) increase over the 200 pound rate in Experiment II(a) and in Experiment I. The reason this was not the case in Experiment II(b) probably is because the 400 pound fertilizer rate resulted in a different reaction on soil I than on the other soils. Instead of increasing the percent phosphorus in the plants, as was the case on soils III, VI and X, this rate on soil I decreased it somewhat although not significantly.

The interaction between soils and fertilizers was significant at the one percent level in the greenhouse but only at the five percent level in the growth chamber. The interactions are shown in Figures 3 and 4, respectively.

In the greenhouse, the changes in the percent phosphorus of the plant material from soils I and VI with increasing amounts of fertilizer are similar; this is also the case with the phosphorus content of the plant material from soils III and X. This would indicate that the interaction was due to the phosphate level rather than the salinity level of the soils.

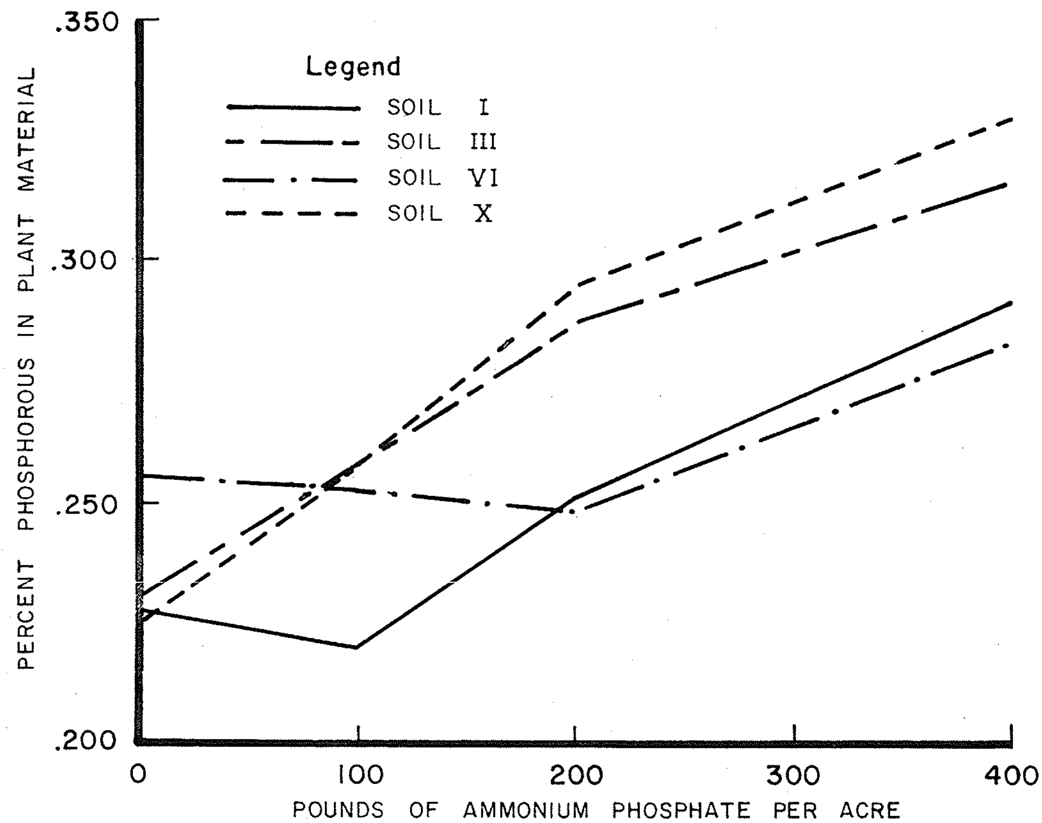

Figure 3. The Variation of the Percent Phosphorus in the Plant Material from Four Soils with Increasing Rates of Phosphorus Fertilizer - Experiment II(a).

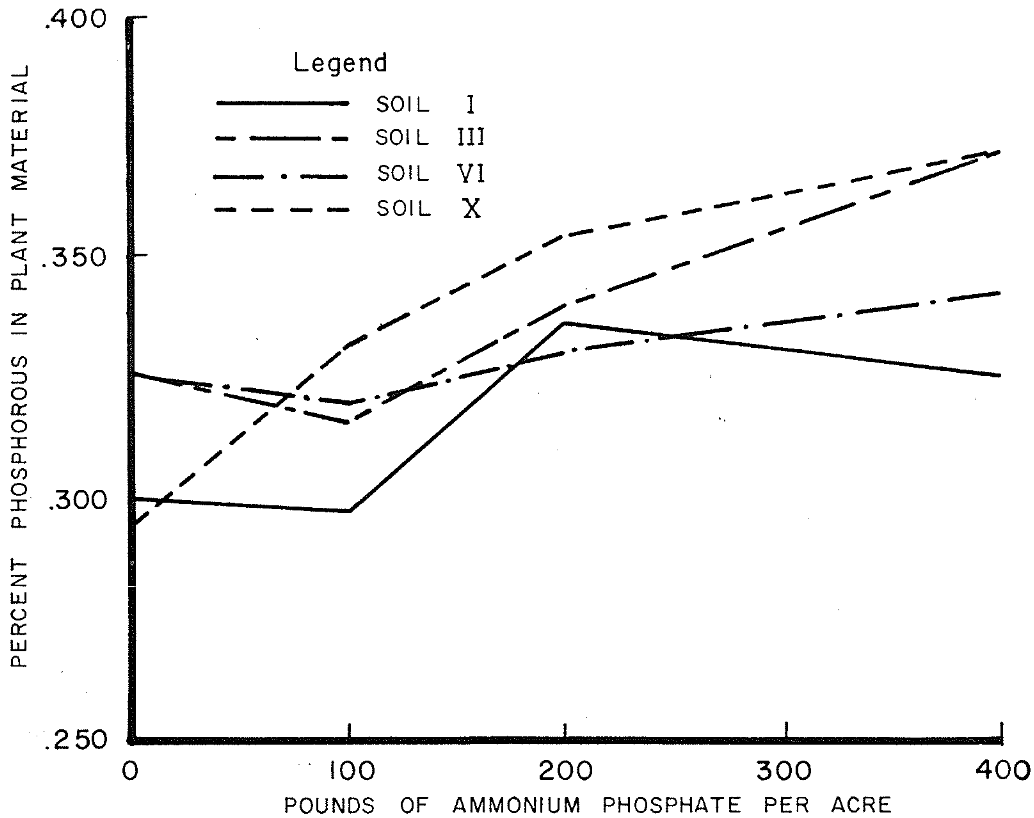

Figure 4. The Variation of the Percent Phosphorus in the Plant Material from Four Soils with Increasing Rates of Phosphorus Fertilizer - Experiment II(b).

In the growth chamber, the interaction is less marked and hence only significant at the five percent level. The effect of the fertilizer on the percent phosphorus in the plant material is the same on all soils with two exceptions. First, on soil I, as mentioned before, the percent phosphorus in the plant material decreased somewhat when the 400 pound rate of fertilizer was applied. The opposite effect was noticed on the other soils. Second, whereas on soils I, III and VI the application of 100 pounds of ammonium phosphate had no significant effect on the percent phosphorus in the plant material, this rate of fertilizer on soil X increased the phosphorus level. The first exception could be attributed to biological dilution. However, the yield response at this rate was no different on soil I than on the other soils, hence, biological dilution did not take place. The second exception may be due to the high extractable phosphorus level initially present in soil X. The exceptions are hard to explain but since the interaction is only significant at the five percent level, they may not really be that important.

Sulfur Uptake

The sulfur content of the plant material of Experiment II is given in Table XVII. The analysis of variance (Table XXV, p. 76) shows that the differences due to soils were significant at the one percent level under the two environmental conditions. In the greenhouse, the differences due to fertilizer treatments were not significant and neither was the interaction between the soil and fertilizer treatments. In the growth chamber, on the other hand, these two factors affected the sulfur

TABLE XVII

AVERAGE SULPHUR CONTENT IN PLANT MATERIAL - EXPERIMENT II
(mgm. sulfur per gm. of oven dry material)

(a) Greenhouse

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
check	2.31	2.33	4.51	7.95	4.27
100	2.75	2.94	4.25	7.62	4.39
200	2.88	2.86	3.83	7.16	4.18
400	2.70	2.72	3.29	6.03	3.73
Soil average	2.66	2.71	3.98	7.23	

Soils L.S.D. @ 1% = .74
@ 5% = .56

(b) Growth Chamber

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
check	3.17	4.63	8.79	30.05	11.95
100	4.22	4.47	7.19	25.51	10.35
200	3.76	4.62	4.99	23.41	9.20
400	3.81	3.82	4.34	21.55	8.38
Soil average	3.74	4.39	6.62	25.13	

Soils and fertilizers L.S.D. @ 1% = 1.99
@ 5% = 1.49

Soils x fertilizers L.S.D. @ 1% = 5.63
@ 5% = 4.22

content of the plant material significantly at the one percent level.

In both the greenhouse and the growth chamber, the sulfur content of the plants from soils I and III were not significantly different. The plants from soil X had a significantly (P = .01) higher sulfur content than the plants from soil VI, both of which had a significantly (P = .01) higher sulfur content than those from soils I and III.

These results are not surprising since the major anion in the saturated soil extract was the sulfate ion which increased markedly with increasing salinity. However, it is of interest to note that in Experiment II(a) and II(b) an increase in the sulfate concentration of the saturated soil extract from 659 p.p.m. to 2603 p.p.m., as occurred between soils I and III (Table IV, p. 16), did not increase the sulfur content of the plant material significantly. On the other hand, under the conditions of Experiment I (Table V, p. 18), which were intermediate between the two environmental conditions of Experiment II, the sulfur content of the plant material from soils I, III and VI did not vary significantly even though the sulfate concentration of the saturated soil extracts increased from 330 to 4763 p.p.m. Not until the sulfate concentration reached the level of that in soil X was there a significant increase in the sulfur content of the plant material.

The data in Table XVIII shows that the total sulfur absorbed by the plants also increased with salinity. The interesting fact here is that, not until the sulfate concentration of the soil solution reached the level of that in soil X, did the total sulfur content of the plant material from both parts of Experiment II increase substantially.

TABLE XVIII

TOTAL SULFUR ABSORBED BY PLANTS - EXPERIMENT II

(a) Greenhouse

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
		mgm. of S.			
check	11.01	13.56	18.36	33.07	18.96
100	16.50	18.55	20.87	39.24	23.80
200	17.31	18.36	20.49	37.59	23.35
400	16.12	17.71	18.26	33.71	21.42
Soil average	15.19	17.05	19.44	35.40	

(b) Growth Chamber

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X	Fertilizer average
		mgm. of S.			
check	7.89	11.67	13.80	39.37	18.56
100	12.58	12.61	14.24	41.07	20.07
200	11.62	12.43	10.48	42.14	18.95
400	11.05	11.69	9.24	46.12	19.55
Soil average	10.78	12.04	12.33	41.95	

The plants in Experiment II(b) had a significantly (P = .01) higher level of sulfur than those in Experiment II(a) (Table XXVIII, p.79), which was probably due to the higher transpiration ratio in Experiment II(b) (Table V, p. 18). Muenscher (32) and others are of the opinion that variations in the rate of transpiration by plants does not affect the amount of salt absorbed. However, the transpiration ratios in Experiment II(b) were considerably higher than those in Experiment II(a) and hence, the results of this experiment are contrary to the above mentioned opinions. The conclusion could be drawn that salt uptake is related to transpiration rates of plants which is in agreement with results reported and conclusions drawn by Bernstein and Hayward (2), Freeland (13), and Wright and Barton (47).

The total amount of sulfur absorbed by the plants in Experiment II(b) was less than that absorbed by the plants in Experiment II(a) on all but soil X. The difference between Experiment II(a) and II(b) was probably due to the much reduced total growth in the growth chamber as reported under the discussion of yield results. The extremely marked increase in the sulfur content of the plants on soil X when subjected to the climatic conditions of the growth chamber resulted in a higher total sulfur uptake compared to the greenhouse, even though the plant growth decreased.

The argument that an increase in the transpiration rate increases the sulfur absorption of the plants does not seem to hold true when the plant material from soil X of Experiment I is compared with the plant material from soil X of Experiment II(a). Under the conditions of Experiment I, where the transpiration ratio was 468 grams water per gram dry plant material, plants from soil X contained only 6.11 mgm. sulfur per gram of dry plant material, whereas, plants on soil X in Experiment II(a), where the average transpiration ratio was 281 grams water per gram dry plant material, had a sulfur content of 7.23 mgm. This deviation probably occurred because under the conditions of Experiment I the higher rates of fertilizer reduced the sulfur content of the plants significantly resulting in an average sulfur content lower than that of the plants in Experiment II(a) where the fertilizer did not have a significant effect on the sulfur content of plants from soil X.

The fact that the differences due to fertilizer treatments in Experiment II(a) were not significant is in agreement with the results reported under Experiment I. The significant effect of the fertilizer on the sulfur content of the plants in Experiment II(b) again can be attributed to the significant ($P = .01$) interaction between soils and fertilizers. The fertilizer treatments had no significant effect on the sulfur content of the plants from soils I, III and VI, although there was a gradual decrease in the sulfur content of the plants from soil VI. However, the sulfur content in the plants from soil X decreased significantly with increasing rates of fertilizer applied. If this had not been the case, the fertilizer differences probably would not have been significant. By substituting the interaction mean square for the error mean square in calculating the fertilizer F-value, the F-value is not significant.

Although the fertilizer differences as such were not significant, the interaction between soils and fertilizers in Experiment II(b) was significant. The interaction is shown diagrammatically in Figure 5. The sulfur content of the plant material from soils VI and X decreased as higher rates of fertilizer were applied. However, the sulfur content of the plant material from soil I increased slightly, although not significantly, and from soil III remained fairly constant as more fertilizer was applied. These results are fairly similar to the ones reported under Experiment I. Presumably, under the conditions of the greenhouse in Experiment II, the sulfur uptake was so low that the fertilizer did not reduce it significantly.

The significant decrease in sulfur content of the plant material from soil X in the growth chamber with increasing rates of fertilizer seems to have resulted in a proportionately greater yield response. Comparing the percent yield of the four soils (Table XIX), the following observations can be made. The yield response of oats to fertilizer on soil III is fairly low (percent yield is high) probably due to the somewhat higher $NaHCO_3$ extractable phosphorus level in soil III compared to soil I. Soils I and VI had very similar phosphorus levels but the oats showed a greater yield response to fertilizer (lower percent yield) on soil VI than on soil I which may be due to the decrease in the sulfur content with increasing rates of fertilizer. The yield response of oats to fertilizer on soil X is even greater, especially at the 400 pound rate. This is surprising when one considers the considerably higher phosphorus level of soil X as compared to the other soils. Maybe the proportionately greater yield response on soil X with its high initial phosphorus level actually due to the decreased sulfur content in the

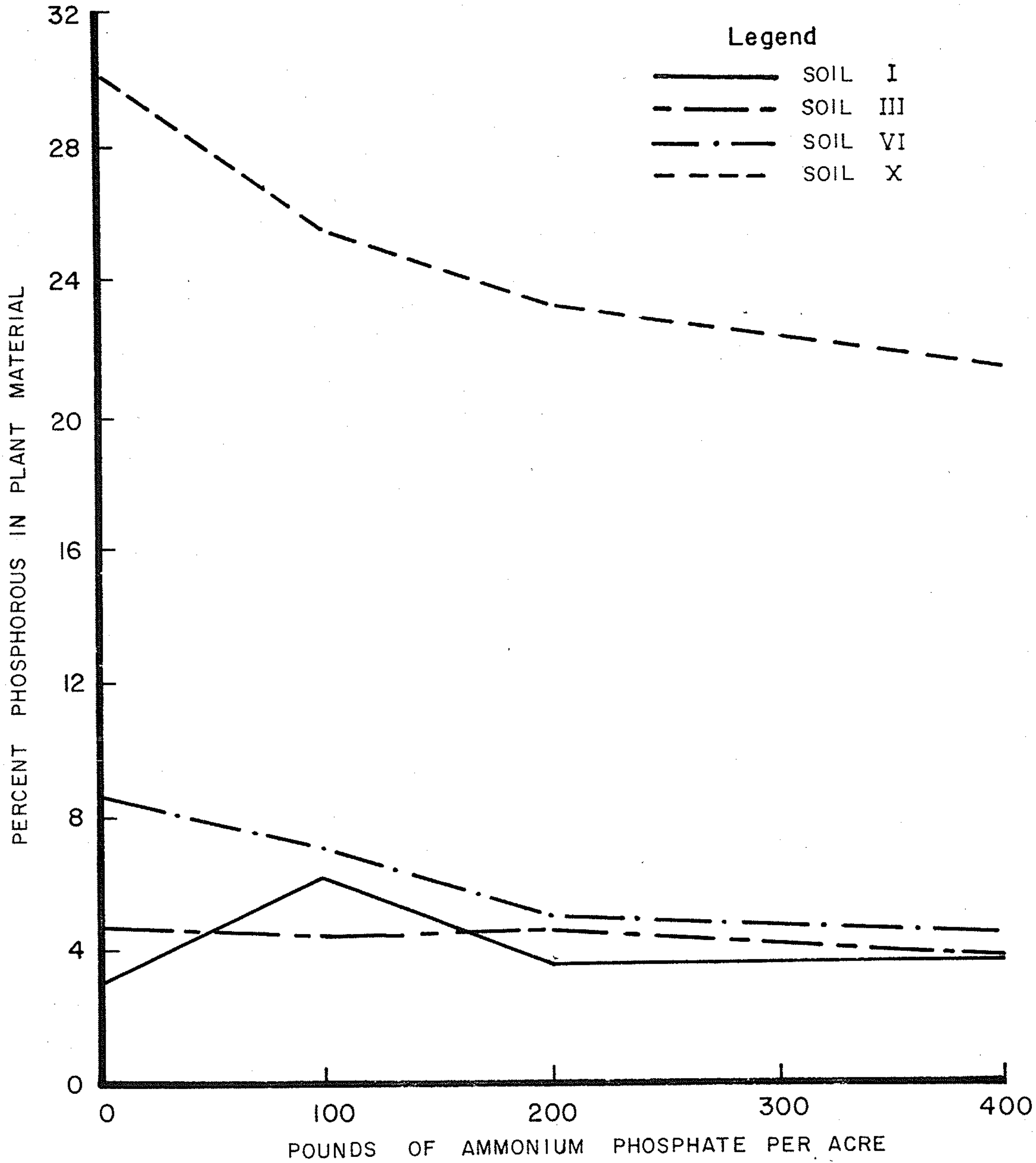

Figure 5. The Variation of the Sulfur Content in the Plant Material from Four Soils with Increasing Rates of Phosphorus Fertilizer - Experiment II(b).

TABLE XIX

PERCENT YIELD RESPONSE[1] - EXPERIMENT II(b)

Fertilizer lbs. 11-48-0/ac.	Soils I	III	VI	X
100	83.89	89.36	79.29	81.36
200	80.90	93.68	74.76	72.77
400	86.21	82.35	73.70	61.21

[1]Percent Yield = $\frac{\text{Check yield}}{\text{Fertilizer yield}} \times 100$

plant material. Such a conclusion would be in agreement with that drawn by Fine and Carson (12).

Although the decreased sulfur content with increasing fertilizer rates in the plant material from soil X may have resulted in a relatively greater yield response, the sulfur concentration was not the only factor active in determining yields. This is illustrated by comparing the yield of oats on soil VI and X at the 400 pound level of phosphate fertilizer (Table XII, p. 38). The yields are almost identical; however, the sulfate content (Table XVII, p. 52) of the plant material from soils VI and X is 4.34 and 21.55 mgm. per gram dry matter, respectively.

GENERAL DISCUSSION

The yield data of the two experiments, as shown on Tables VI and XII on pages 22 and 38, respectively, indicate that the absolute response of oats to phosphorus fertilizer did not differ between the four soils under any of the three environmental conditions. When the yield response is expressed as a percentage of check yield over fertilized yield (Table XIX, p. 59) there is some indication that the growth chamber plants growing on soils VI and X did respond more to the fertilizer applied than did the plants on soils I and III. Generally, however, the results of this investigation are contrary to those reported by Fine and Carson (12) and Ferguson (11). This is probably due to one of two reasons.

Investigations conducted by Fine and Carson (12) showed that the typical salt damage symptoms of necrosis and tip burn were alleviated by additions of phosphate fertilizer. They concluded that this may have been one reason for the marked growth response they obtained with cereal crops growing on saline soils when fertilized with phosphate fertilizer. However, under the conditions of this investigation abnormally high yields were obtained from the saline soils and the normal salt damage symptoms did not develop. This may have been one reason why the results of this investigation do not agree with those reported above.

The relatively high $NaHCO_3$ extractable phosphorus levels in the soils used may have been another reason why a greater response was not obtained on the saline soils than on the non-saline soils. Whereas, Fine and Carson used soils with extremely low available phosphorus levels the soils used in this investigation had relatively high levels of available phosphorus and hence the results of the two investigations are different.

The addition of phosphate fertilizer reduced the sulfate ion concentration in the plants from soils VI and X but not enough to result in a greater growth response than what was obtained on soils I and III. If the absorption of both the sulfate and phosphate ions is via a carrier substance as described by Leggett and Epstein (24), and Hagen and Hopkins (21), it is conceivable that an increased phosphate concentration in the soil solution could reduce the sulfate ion uptake by the plants simply by competing with the sulfate ion for the binding sites on the carrier complex. This then would reduce the toxicity of the sulfate ion to the plant and cause a marked growth response. This growth response was not obtained probably because the available soil phosphorus level was high to begin with and the conditions in the greenhouse did not result in any large amount of sulfate being absorbed.

In Experiment II(b) the sulfur concentration in the plant material decreased when phosphate fertilizer was applied (Table XVII, p. 52). This was most noticeable in the plant material from soils VI and X and seems to have resulted in a greater percent yield response than what was obtained on soils I and III (Table XIX, p. 59). These results are similar to those reported by Ferguson (11). He obtained higher percent yield responses on saline soils as compared to non-saline soils even when the $NaHCO_3$ extractable phosphorus was as high as fourteen p.p.m. His results were obtained under field conditions which in all probability approximated the conditions in the growth chamber more closely than those in the greenhouses. He suggested that his results possibly were due to a reduced salt concentration in the fertilized plants. Therefore, it seems probable that under either extremely low available phosphorus levels or under relatively heavy transpiratory stress phosphate fertilizer will reduce the sulfate or total salt concentration in the plants growing on saline soils and cause a greater positive growth response than when applied to plants growing on non-saline soils.

The variations in the A-values of the soils could in most cases be attributed to differences in root development or differences in $NaHCO_3$ extractable phosphorus levels. Fried et al. (15) suggest that the phosphorus uptake by plants is limited by the slowest of the following two reactions:

1) P soil (unavailable) $\rightleftharpoons$ P solution (available)
2) P solution $\dashrightarrow$ P (inside plant)

Their experiments indicated that the first reaction should not be limiting since the soil used was capable of supplying enough phosphorus in two to three hours to meet the total requirement of most crops. Hence, they concluded that the rate of phosphorus absorption by the plants was governed by the concentration of the phosphorus in solution in contact with the roots. The rate of phosphorus movement in the soil will limit this volume. However, under soil conditions at or near field capacity and with a limited volume of soil for root development, as was the case in these experiments, the rate of phosphorus movement should not have limited the amount of solution in contact with the roots. Hence, the second equation probably was the limiting factor to phosphorus uptake by the plants and this should affect fertilizer phosphorus as much as soil phosphorus. Therefore, A-values probably were of little value in trying to evaluate soil phosphorus availability in this experiment. If the salinity of the soil affects the plant's ability to absorb phosphorus it is not measurable by this technique.

As shown in Tables VIII and XV (p. 29 and p. 44) the phosphorus concentration in the plants was not affected by the salt concentration in the soil solution. On the other hand the total amount of phosphorus taken up by the plants decreased with increasing soil salinity under two of the three environmental conditions (Table IX, p. 29 and Table XVI, p. 47) but this could be accounted for by decreased total growth.

These results need not be surprising, since, studies designed to measure the competitive effect of various ions on phosphorus absorption (3, 17, 21) failed to show a competitive effect on phosphorus absorption by either $SO_4^{=}$, Cl^- or NO_3^- anions. The predominant anions in the soil solution were sulfates and chlorides and hence, no reduction in phosphorus absorption need have been expected. Hagen and Hopkins (21) suggest that very few anions compete for the phosphorus binding sites on the carrier substances which are active in absorbing phosphorus. The OH^- ion apparently does (3, 21) but since the pH of all soils used never exceeded 8.0, this anion probably was not present in sufficient amounts to affect the phosphorus absorption mechanism. Breazeale and McGeorge (3) and Fine and Carson (12) both report a reduction in phosphorus uptake by additions of Na_2SO_4 to the growth media. The predominantly sulfate ions in the soils of this experiment did not reduce the plant's ability to absorb phosphorus so that it would almost seem as if the sodium ion of the Na_2SO_4 was responsible for the reduced phosphorus absorption reported by Breazeale and McGeorge, and Fine and Carson. This would be in disagreement with Thorne's (38) and Ravikovitch's (34) results as both reported an increase in the phosphorus availability with an increase in the sodium level of the soil. McGeorge (31), on the other hand reports that sodium reduces phosphate availability.

Eaton (7) reports a toxic accumulation of chloride and sulfate ions in plant tissue when these anions are added to the growth media in excessive amounts. Other observations (Hayward and Spurr (22) on flax; and Eaton (7) on tomatoes) have been made indicating specific toxicity of sulfate ions to plants. The data in Tables X and XVII (p. 34 and p. 52) shows that the sulfur concentration in the plant material increased with increasing salinity of the soil. This was most striking under the conditions of the growth chamber. This large increase in the sulfur concentration of the plants from soil X in the growth chamber may have resulted in lower yields. However, the major factor probably was the differential moisture stress between soils.

The phosphate fertilizer decreased the sulfur content of the plants only when they were grown on soils VI or X. If both the sulfate and phosphate ions are absorbed by the plant via a carrier substance, it is conceivable that the phosphate ion from the added fertilizer could replace the sulfate ion on the carrier substance and in this way reduce the sulfate content of the plants. Ferguson (11) suggests "that salt damage is related to the accumulation of salts in the plant tissue and that the rate of accumulation is reduced if the plants are adequately supplied with phosphate." His results seem to bear this out. This explanation, however, would be contrary to the results reported by Leggett and Epstein (24). They report that the phosphate ion has no measurable affinity for the sulfate binding site on the carrier substance.

Lundegardh (29) suggests that the antagonistic effects between anions may be different at various concentrations and may be influenced by time because of the difference between the initial absorption and continuous accumulation. This may explain the differences between the results reported in Tables X and XVII and those reported by Leggett and Epstein (24) since the latter studies were based on three-hour absorption periods, whereas, this study covered a six-week period.

Whatever the reason for the decreased sulfur content in the plants with increasing rates of fertilizer it did not increase the absolute yield of oats any more on saline soils than on non-saline soils. On the other hand, the percent yield increase of plant growth due to fertilizer was considerably greater on soil X in the growth chamber than on the other soils. This is also the only treatment which shows a significant decrease in sulfur content due to applications of phosphate fertilizer. Hence, under conditions of high sulfur absorption, phosphate fertilizer could reduce this absorption and cause a higher yield increase because of it.

CONCLUSIONS

1. Under relatively high $NaHCO_3$ extractable soil phosphorus levels ammonium phosphate fertilizer does not increase the absolute yield of oats any more on saline soils than on non-saline soils.

2. Soil salinity does not affect the ability of the plants to absorb phosphorus.

3. Ammonium phosphate fertilizer tends to decrease the absorption of sulfur by plants growing on saline soils.

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APPENDIX

TABLE XX

ANALYSIS OF VARIANCE ON THE DRY MATTER YIELD DATA - EXPERIMENT I

Sources of error	Sum of squares	d.f.	Mean square	F-value
Soil	98.397	3	32.799	292.85**
Fertilizer	5.877	3	1.959	17.49**
Soil x Fertilizer	.596	9	.066	.589
Error	12.540	112	.112	
Total	117.410	127		

TABLE XXI

ANALYSIS OF VARIANCE ON THE PHOSPHORUS CONTENT DATA - EXPERIMENT I

Sources of error	Sum of squares x 10^{-3}	d.f.	Mean square	F-value
Soil	6.8	3	2.27	10.23**
Fertilizer	170.1	3	56.70	255.41**
Soil x Fertilizer	21.6	9	2.40	10.81**
Error	24.9	112	.222	
Total	223.4	127		

TABLE XXII

ANALYSIS OF VARIANCE ON THE SULFUR CONTENT DATA - EXPERIMENT I

Source of error	Sum of squares	d.f.	Mean square	F-value
Soil	65.18	3	21.73	21.73**
Fertilizer	2.23	3	.73	.74
Soil x Fertilizer	18.50	9	2.06	2.04*
Error	113.06	112	1.01	
Total	198.97	127		

*Significant at the five percent level of probability.

**Significant at the one percent level of probability.

TABLE XXIII

ANALYSIS OF VARIANCE ON THE DRY MATTER YIELD DATA - EXPERIMENT II

(a) Greenhouse

Sources of error	Sum of squares	d.f.	Mean square	F-value
Soils	17.855	3	5.952	46.50**
Fertilizer	13.852	3	4.617	36.07**
Fertilizer x Soil	1.409	9	.157	1.23
Error	6.120	48	.128	
Total	39.236	63		

(b) Growth Chamber

Sources of error	Sum of squares	d.f.	Mean square	F-value
Soils	16.195	3	5.398	96.39**
Fertilizer	2.996	3	.999	17.84**
Fertilizer x Soil	.685	9	.076	1.36
Error	2.681	48	.056	
Total	22.557	63		

TABLE XXIV

ANALYSIS OF VARIANCE ON PHOSPHORUS CONTENT DATA - EXPERIMENT II

(a) Greenhouse

Sources of error	Sum of squares x 10^{-3}	d.f.	Mean square	F-value
Soils	7.3	3	2.433	9.73**
Fertilizer	46.4	3	15.466	61.86**
Soil x Fertilizer	11.5	9	1.277	5.11**
Error	12.0	48	.250	
Total	77.2	63		

(b) Growth Chamber

Sources of error	Sum of squares x 10^{-3}	d.f.	Mean square	F-value
Soils	5.6	3	1.866	5.21**
Fertilizer	17.5	3	5.833	16.29**
Soil x Fertilizer	7.2	9	.800	2.23*
Error	17.2	48	.358	
Total	47.5	63		

TABLE XXV

ANALYSIS OF VARIANCE ON SULFUR CONTENT DATA - EXPERIMENT II

(a) Greenhouse

Sources of error	Sum of squares	d.f.	Mean square	F-value
Soils	220.701	3	73.567	120.99**
Fertilizer	3.940	3	1.313	2.16
Soil x Fertilizer	7.803	9	.867	1.43
Error	29.174	48	.608	
Total	261.618	63		

(b) Growth Chamber

Sources of error	Sum of squares	d.f.	Mean square	F-value
Soils	4976.463	3	1658.821	377.52**
Fertilizer	115.179	3	38.393	8.74**
Soil x Fertilizer	126.841	9	14.093	3.21**
Error	210.900	48	4.394	
Total	5429.383	63		

TABLE XXVI

ANALYSIS OF VARIANCE ON DRY MATTER YIELD DATA
EXPERIMENT II(a) AND II(b) COMBINED

Sources of error	Sum of squares	d.f.	Mean square	F-value
Soil	31.89	3	10.63	115.7**
Fertilizer	14.81	3	4.94	53.6**
Temperature	320.99	1	320.99	10030.94**
Soil x Fertilizer	1.55	9	.172	1.870
Soil x Temperature	2.16	3	.72	7.83**
Temperature x Fertilizer	2.04	3	.68	7.39**
Soil x Temperature x Fertilizer	.54	9	.06	.65
Error	8.81	96	.092	
Total	382.79	127		

TABLE XXVII

ANALYSIS OF VARIANCE ON PHOSPHORUS CONTENT DATA
EXPERIMENT II(a) AND II(b) COMBINED

Sources of error	Sum of squares x 10^{-3}	d.f.	Mean square	F-value
Soil	14.0	3	4.67	15.26**
Fertilizer	59.8	3	19.93	65.13**
Temperature	139.1	1	139.1	454.58**
Soil x Fertilizer	13.7	9	1.52	4.97**
Soil x Temperature	.3	3	.1	.327
Fertilizer x Temperature	4.0	3	1.33	4.35**
Soil x Temperature x Fertilizer	3.6	9	.4	1.31
Error	29.4	96	.306	
Total	263.9	127		

TABLE XXVIII

ANALYSIS OF VARIANCE ON SULFUR CONTENT DATA
EXPERIMENT II(a) AND II(b) COMBINED

Sources of error	Sum of squares	d.f.	Mean square	F-value
Soil	3631.78	3	1210.59	482.31**
Fertilizer	74.97	3	24.99	9.96**
Temperature	1085.41	1	1085.41	432.43**
Soil x Fertilizer	97.03	9	10.78	4.29**
Soil x Temperature	1565.38	3	521.79	207.88**
Temperature x Fertilizer	44.15	3	14.72	5.86**
Soil x Temperature x Fertilizer	37.61	9	4.18	1.67
Error	240.59	96	2.51	
Total	6776.92	127		

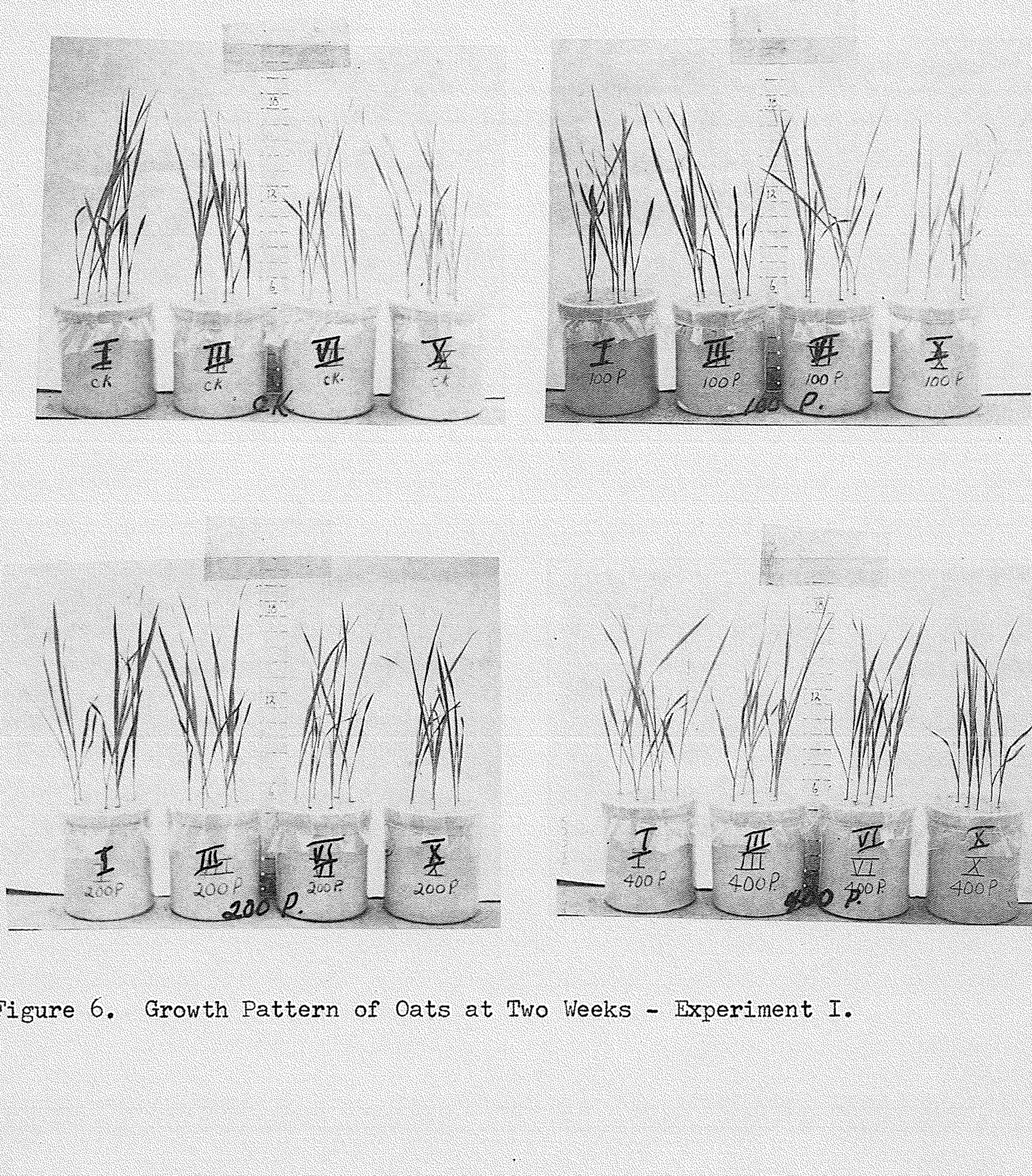

Figure 6. Growth Pattern of Oats at Two Weeks - Experiment I.

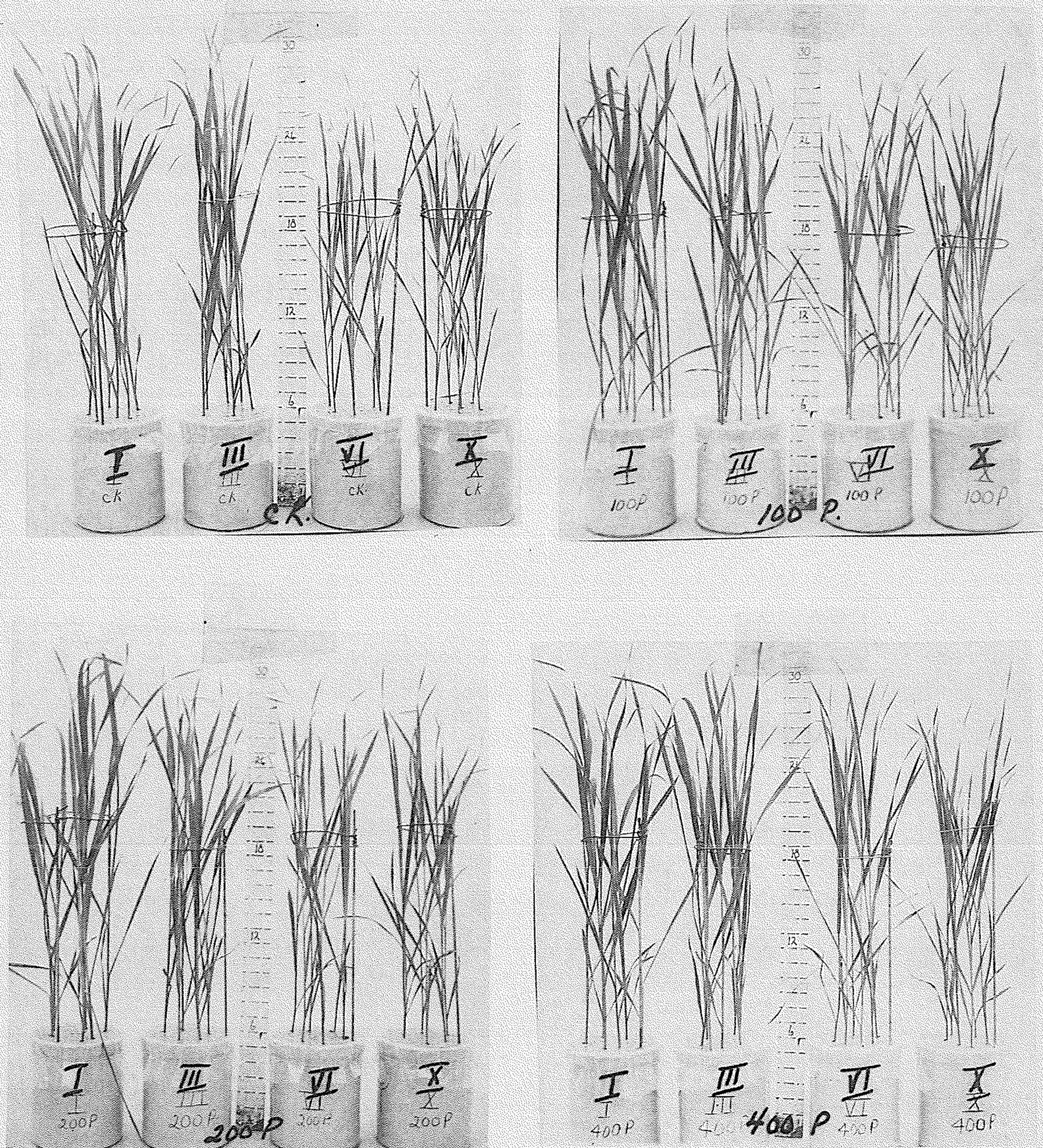

Figure 7. Growth Pattern of Oats at Four Weeks - Experiment I.

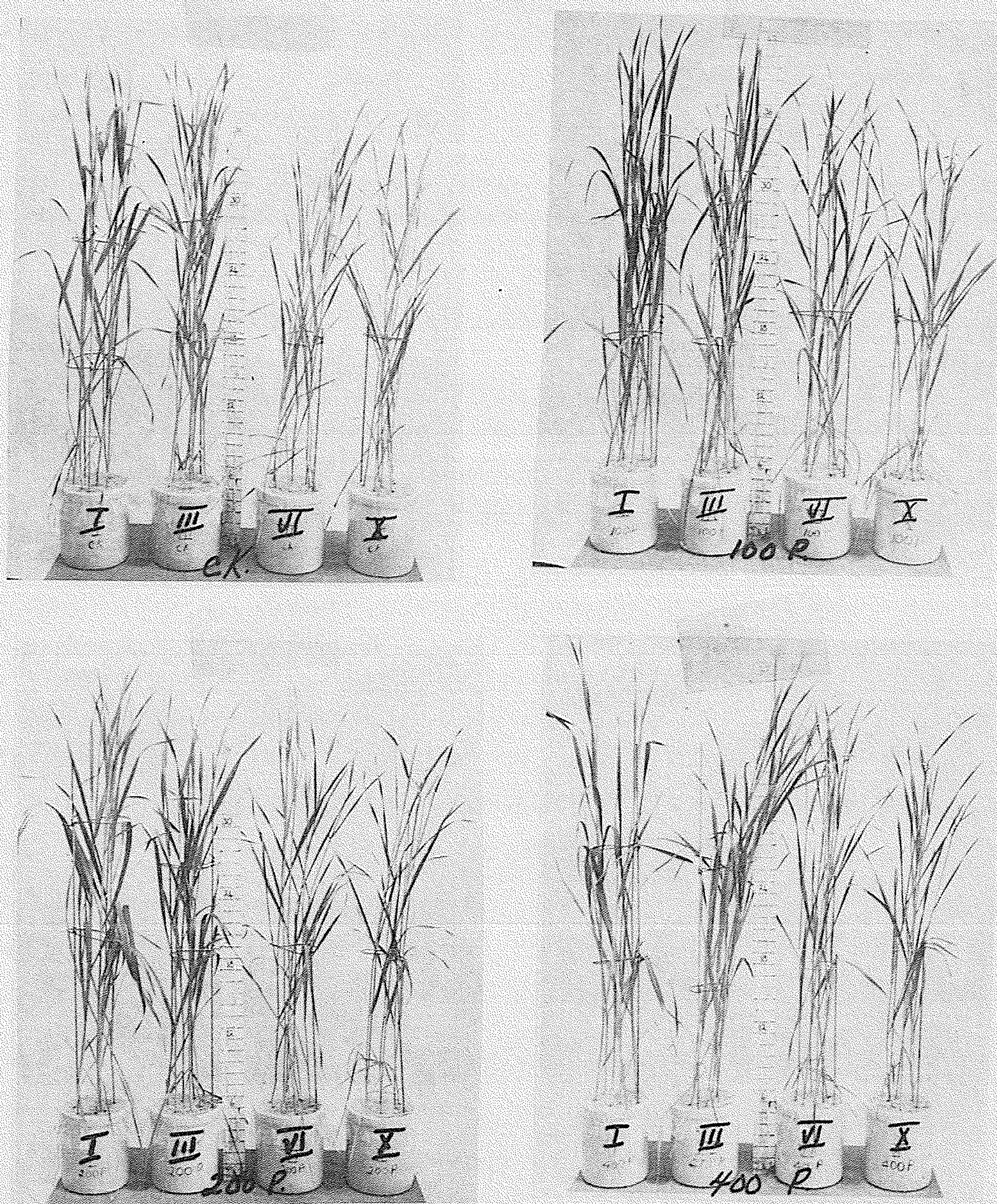

Figure 8. Growth Pattern of Oats at Six Weeks - Experiment I.

Figure 9. Growth Pattern of Oats at Two Weeks - Experiment II.

Figure 10. Growth Pattern of Oats at Four Weeks - Experiment II(a).

Figure 11. Growth Pattern of Oats at Four Weeks - Experiment II(b).

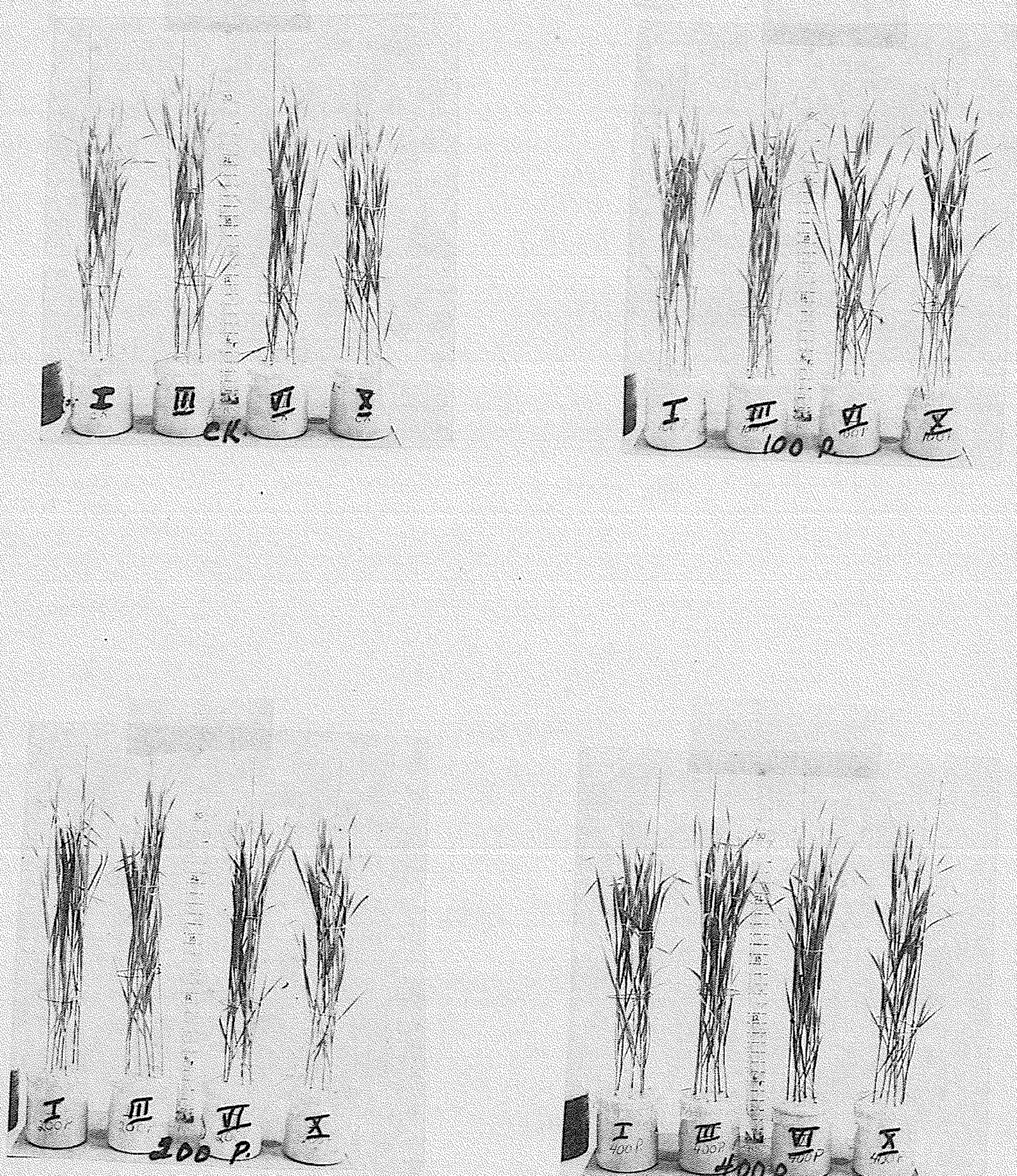

Figure 12. Growth Pattern of Oats at Six Weeks - Experiment II(a).

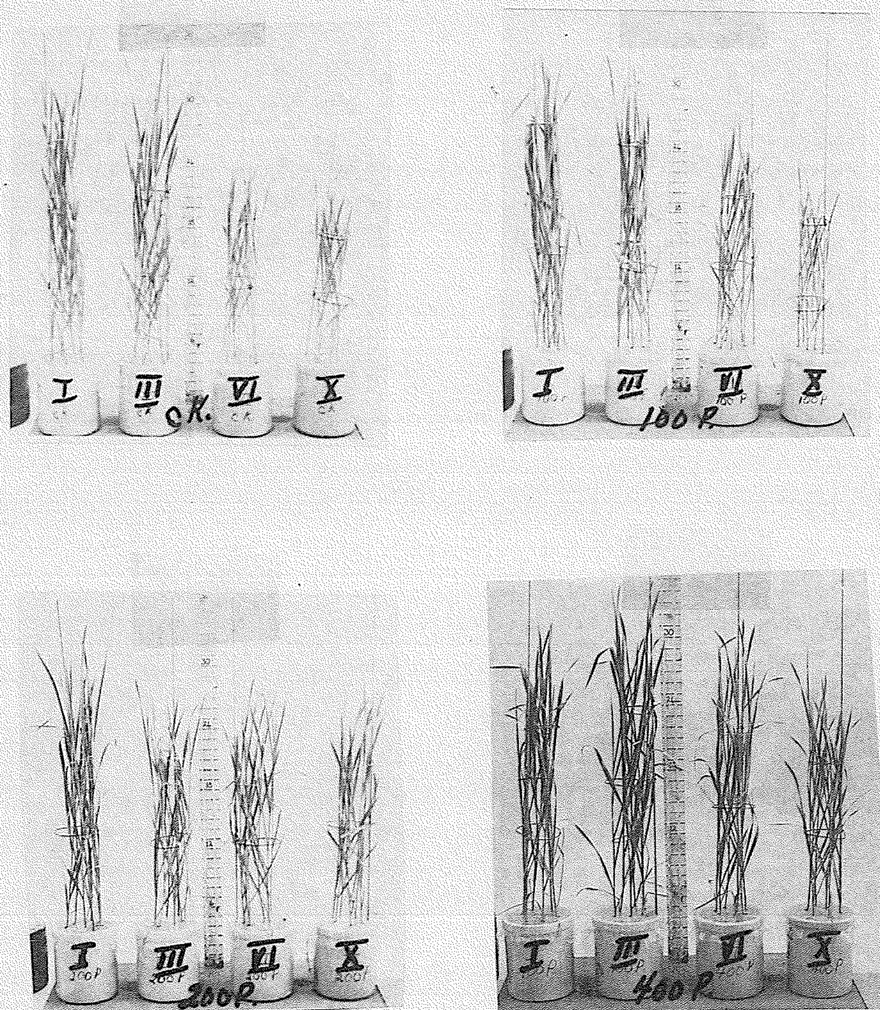

Figure 13. Growth Pattern of Oats at Six Weeks - Experiment II(b).