# THE INFLUENCE OF SEVERAL PHYSICAL SOIL FACTORS ON THE DEVELOPMENT AND ACTIVITY OF PLANT ROOTS

Thesis for the Degree of Ph. D.

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Thomas Walter Scott

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**This is to certify that the**

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R. Earl Erickson
**Major professor**

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By

Thomas Walter Scott

AN ABSTRACT

Submitted to the College of Agriculture
Michigan State University of Agriculture and
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ABSTRACT

Investigations were conducted to study the influence of several physical soil factors on the development and activity of plant roots.

Preliminary studies involved the consideration of a non-radioactive tracer to study root activity. Also, preliminary work was done with a radioactive tracer to study rooting patterns of crops under field conditions.

Absorption of non-radioactive Rb from different soil depths by corn was compared with absorption of $P^{32}$ placed at similar depths in the soil. It was found that the pattern of absorption of the two tracers was quite similar for various stages of corn growth.

Preliminary work was done with radioactive tracers in field studies involving sugar beet and corn root systems. Patterns of root growth and root activity were established at various ages of growth of the plants. Actual corn root weights sampled from positions in the soil similar to where $P^{32}$ had been placed compared favorably with amounts of labeled phosphorus absorbed.

A greenhouse study was conducted to determine the effect of compaction on the vertical growth of roots. Absorption of $P^{32}$ indicated that bulk densities up to 1.46 in a Sims clay loam did not restrict root growth.

Compacted subsurface layers with a bulk density of 1.95 (in greenhouse containers) restricted the penetration

of sugar beet and tomato roots but did not stop penetration by alfalfa tap roots. When peroxide, as a source of oxygen, was mixed with the compacted layers, sugar beet roots penetrated the zone of compaction. Fibrous root development on alfalfa tap roots was increased significantly because of peroxide treatment.

Differences in corn root patterns as affected by tillage methods on a Kalamazoo soil were established using tracer techniques. Eighteen inch disc plowing caused considerable increase in root activity at 12 and 18 inch depths. Corn yields were also increased substantially on plots which had received 18 inch disc plowing.

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# I. INTRODUCTION AND OBJECTIVES

Plant species have characteristic patterns of root development just as they have characteristic development of aerial portions, but soil factors may have a pronounced effect on the development of root systems. The general behavior of plant roots in the soil is a function of many variables. Important soil factors which influence root systems are: moisture, oxygen supply, quantity and distribution of available nutrients, hydrogen-ion concentration, texture, structure and bulk density.

Since plant roots develop in the soil, they are not as easy to investigate and observe as aerial portions of plants. Investigations on the root systems of crops growing in the field are difficult to carry out and as a result of this our knowledge of the interaction between soil and plant is rather limited.

Recent advances in instrumentation (40, 70) and technique (30) have made possible a more accurate evaluation of individual physical factors affecting plant roots. However, it is often difficult to evaluate measurements of physical soil factors because complex interactions frequently occur. This often restricts the quantitative evaluation of individual physical factors.

A study of root penetration and development in soils would not be complete until consideration is given to the quantity and availability of various nutrient elements. At the present time, soil tests are based largely on surface soil measurements, that is, the fertility status of soils is evaluated from soil samples taken from a 0-6 inch soil depth. This sampling procedure is conventional even though it is known that the various subsurface layers may contribute large amounts of plant nutrients for crop growth. A more thorough knowledge of the characteristics of the various soil horizons and absorption of nutrients by roots therein would lead to a more accurate interpretation of soil tests. In addition, a more efficient use and placement of fertilizers might be realized.

In many subsoils, nutrient reserves may remain unavailable to plants unless some alteration in physical condition occurs such as improved aeration, lowering of the bulk density of the lower horizons, etc. which will allow the roots to develop. Thus, the mere fact that available nutrients are in abundance and/or roots occur in a given horizon does not necessarily mean nutrients are being taken up from this zone in large quantities. According to Bonner and Galston (10) and Meyer and Anderson (46) the mere presence of roots in a soil zone does not necessarily mean nutrient accumulation is taking place in the root. These authors state that salt accumulation takes place, for the most part, in cells which are capable of cell division and growth while root hairs provide the main entrance for water into the plant. As cells lose their capacity for elongation, they also lose most of their ability for mineral salt accumulation.

This study included both greenhouse and field experiments. The objectives of the field studies were:

A. To use tracer techniques in an attempt to determine the distribution of actively growing corn and sugar beet roots at different stages of growth and to compare such root density patterns with the weights of roots sampled from different depths.

B. To study the effects of various tillage methods on root development of corn in a Kalamazoo sandy loam soil by measurements of bulk density and patterns of root distribution as measured by radioactive technique.

The objectives of the greenhouse studies were:

A. To make a preliminary investigation of root patterns in soils using non-radioactive rubidium.

B. To investigate the effect of compaction on the vertical distribution of corn roots.

C. To determine if mechanical impedance or lack of oxygen restricts root growth in subsoils which have a high bulk density.

# II. LITERATURE REVIEW

A knowledge of root systems is fundamental to such studies as soil aeration, soil-moisture relationships and the scientific applications of fertilizers (69). A thorough understanding of the extent and distribution of roots of specific crops should furnish the basis not only for time and amounts of fertilizers applied but also the method and depth of its application according to Hall (30).

## A. Methods of Studying Root Growth and Root Activities

Weaver (68, 69) has done extensive work concerning the growth and development of plant roots. Although many of his studies were conducted over thirty years ago, Weaver's findings concerning the distribution of roots are probably the most reliable today. The technique used by Weaver to evaluate the root distribution of many crops involved digging trenches at least 5 feet deep beside the plant under investigation. Various hand tools were then used to follow the course of the roots throughout the soil profile.

A quantitative study of entire root systems was accomplished by Pavlychenko (51). This method involved excavating large blocks of soil which included the entire root system. The blocks of soil were then elevated to the surface and the soil carefully washed away to expose the entire root system.

Field core sampling of roots has been done by Haas (29) and others. The method of Haas involved using a tube approximately 5 inches in diameter and 17 inches long. This was driven into the soil from the surface for quantitative root studies.

In addition to the field excavation, soil block methods and field core sampling for studying plant root systems, another group of methods has been recently used. These procedures can be listed as tracer methods utilizing both non-radioactive and radioactive isotopes. In principle, all involve the placement of the tracer at different depths in the root zone of plants before or during the development of the plant root system. Analyses of the aerial parts of the crop (usually leaves) for the tracer at different stages of growth are considered to be an indication of the density of actively absorbing roots in specific soil horizons.

Non-radioactive tracers by necessity must first be ions or isotopes which are not normally found in appreciable quantities in soils. Secondly, they must be absorbed similarly to nutrient ions normally taken up in appreciable quantities by plants.

Radioactive isotopes are ideally suited to tracer studies of root systems since it is possible in some cases to use the active isotope of a nutrient which is absorbed in appreciable amounts by plants.

To be of real value in evaluating the nature of plant root patterns, especially over a period of time, all nutrient tracers once placed at a certain soil depth, should remain in a limited zone.

Sayre and Morris (60) placed lithium chloride at various locations in the soil adjacent to locations of crop roots. This was accomplished by removing a soil core, mixing the salt with the soil and then replacing the soil. Plant leaves were then analyzed for lithium by spectroscopic methods. The relative quantity of lithium found in the plant leaves by spectrographic analysis was considered to be a measure of the root activity at different stages of growth. However, the method had limited applications in that only small quantities of lithium were recovered and the manual labor required for its placement in the soil at the required depths was high.

The methods thus far described have the distinct disadvantage in that the number of observations that can be made is small because of the labor involved and information on the absorptive action in the soil is rather incomplete.

Hall, et. al (30) proposed a technique utilizing radioactive phosphorus to determine the extent and relative activity of plant roots. This method consists of injecting small quantities of radioactive phosphorus at given distances away from and below the plant. Then the activity of the aerial portions of the plant are determined at different stages of plant development. The results from this study indicated large differences in the root patterns of corn, cotton, peanuts and tobacco. It is possible that the data obtained in this way can be used to estimate the fertilizer application pattern for soils and the volume of soil from which the plant is extracting most of its water. An important characteristic of $P^{32}$ is that once placed in the soil the element is relatively immobile and upon absorption it is distributed vertically in the plant.

Tracer techniques utilizing $P^{32}$ were used by Metzger and Lawton (45) and Lawton, Tesar and Kawin (39) in establishing root patterns of alfalfa by placing radioactive superphosphate fertilizer at various depths.

Sanders, Lawton and Robertson (59) used a technique similar to the one suggested by Hall to study the effects of subsoiling on the root activity of corn plants.

Murdock and Engelbert (48) conducted studies in Wisconsin to determine the depth to which the corn plant feeds under field conditions. The investigations indicated that corn roots absorb a large percentage of their phosphorus from soil depths occurring below the plow layer. It was pointed out in this study that the total soil phosphorus in the soil layers below the plow layer was of greater magnitude than the amounts occurring in the surface 6 inches.

### B. Effect of Deep Tillage and Bulk Density on Root Growth and Activity

In the development of plants, roots perform distinct functions such as anchorage, absorption, conduction and storage. These functions may be limited by certain soil conditions. The effect of mechanical impedance on root growth had drawn considerable attention. Different methods of tillage, including the use of dynamite, have been used in an attempt to break up soil layers of high bulk density either of natural or man made origin. However, the value of various depths of tillage is judged almost entirely by the increase or decrease in growth and yield of the above ground portions of plants.

Veihmeyer and Hendrickson (67) conducted experiments to determine the threshold density, above which sunflower roots were unable to penetrate soils. These workers stated that bulk densities above which roots do not penetrate is not necessarily the same for all soils and that no roots were found at densities of 1.9 or above. In clay soils however, there was no root penetration when the density reached 1.6 or 1.7. It was also concluded that sandy soils, which are generally considered easy to work, may be compacted at a depth varying with the type and weight of the tillage implement used.

The adverse effect of dense subsoils on growth of corn was shown in a study by Bertrand and Kohnke (8). According to their results, corn roots did not penetrate a silt loam subsoil having a bulk density of 1.5, but did grow profusely in subsoils with a density of 1.2. Fertilization did not aid root penetration into the dense soil layers.

Over a five year period Engelbert and Truog (23) investigated root penetration on a strongly acid, Almena silt loam soil which has a tight subsoil. It was concluded that subsoiling, liming, and fertilizing permitted deeper root penetration by alfalfa. However, deeper root penetration did not occur as a result of subsoiling alone. Their results suggest that a low fertility status in the subsoil discourages root distribution in lower soil layers and that consequently crop yields are affected.

### C. Effects of Soil Aeration on Root Development and Activity

Numerous reviews on the subject of soil aeration have appeared in the literature. These include reviews by Russell (58), Meyer and Anderson (46), Bonner and Galston (10), Kramer (33), Bauer (7) and Peterson (54).

According to Russell (58) the importance of the soil atmosphere has been wisely accepted but has received relatively little attention by investigators. He also states that considerable evidence indicates that cultural practices bring about changes in the physical properties of soils but there is a lack of quantitative evidence to support the contribution of the individual factors to aeration.

Results of a number of experiments on the effect of relatively low oxygen concentrations were reported by Cannon (16). Conclusions were drawn covering a large number of species and based on observations of rates of root growth measured over short periods of time. (Cannon concluded that root growth at various levels of oxygen was strongly influenced by temperature.)

According to Russell (58) roots growing under conditions of good aeration are long, light colored, and well supplied with root hairs. Where insufficient quantities of oxygen are present, the roots are thickened, shorter, darker, and have less than the normal number of root hairs. Thus properly aerated roots will have a greater root surface over which to absorb water and nutrients.

Peterson (54) noted that plant species differ in oxygen requirements and that the oxygen requirement varied with changes in temperature. Bertrand and Kohnke (8) observed quantitatively that oxygen diffusion was slower in dense subsoils compared to diffusion in loose subsoils. They also noted that high moisture content intensified the restricting effects of dense subsoils. According to their conclusions restricted root growth by a dense subsoil is partly the result of the subsoil acting as a mechanical impedient and partly due to the lack of oxygen in the subsoil.

In a study by Gill and Miller (28) it was observed that normal root growth was adversely affected by reduction of the oxygen content to ten percent. Where the roots were not subjected to a mechanical barrier, growth continued at concentrations as low as one percent of oxygen.

Cline (19) found that roots of field pea plants grown under oxygen stress were thicker, smaller and less fibrous in comparison to those grown under optimum conditions of aeration.

According to Lemon and Erickson (40) active root surfaces are covered with a water film and since oxygen is only slightly soluble in water, the oxygen diffusion rate in soils is the important factor and not necessarily the absolute percent oxygen. Diffusion through the liquid phase is much slower than through the gaseous phase and as a result, the thickness of the water film on the root is quite important to the oxygen flow.

Melsted, Kurtz, and Bray (44) found that oxygen dificiencies actually may occur under heavy plant populations even on soils that are considered well aerated. In this study, growth and yield responses of corn and soybeans to hydrogen peroxide applied to the soil at weekly intervals were taken as criteria of the need for additional oxygen. The authors concluded that suitable oxygen carriers, applied as fertilizers, might be worthwhile in stimulating the growth and yield of plants.

Wiersma and Mortland (71) have shown that oxygen can be a limiting factor in the growth of sugar beets, and its deficiency may be corrected by the use of peroxides. Length of beet was increased through the use of calcium peroxide.

# III. EVALUATION OF TECHNIQUES TO MEASURE ROOT DISTRIBUTION AND ACTIVITY

## A. The Comparison of Non-Radioactive Rubidium and Labeled Phosphorus as Indicators of Root Distribution and Root Activity

(1) <u>Purpose</u>

This experiment was conducted to determine if non-radioactive Rb, placed at different depths in soil, might be used as an indicator for plant root distribution and activity. A study utilizing $P^{32}$ at soil depths comparable to Rb placement was conducted at the same time to provide a basis for evaluation of Rb uptake by plant roots.

(2) <u>Methods of procedure</u>

This study was conducted in the Plant Science Greenhouse on the Michigan State University campus. The soils used in this experiment were: (1) an Oshtemo sandy loam from the Rose Lake Conservation Area, Clinton County, Michigan and (2) a Miami loam from the R. L. Cook Farm in Clinton County, Michigan.

Both soil materials were collected in the fall of the year in four samples from 6 inch depth increments down to a depth of 24 inches. This soil was then air dried and passed through a quarter inch mesh screen. This screening served the purpose of removing trash and other coarse materials.

After screening, the soils were then placed in glazed drain tile 10 inches in diameter and 24 inches in length. The soils were placed in the tile in 6 inch increments representative of their occurrence with depth under field conditions.

To provide optimum amounts of nitrogen and phosphorus in the soil for plant growth, fertilizers were added to the surface 6 inches of soil as recommended in Extension Bulletin 159. Amounts of fertilizer for greenhouse use were doubled. Potassium was omitted from the added fertilizer where Rb was added in the treatments. However, potassium was added to the two soils which received the $P^{32}$ treatments. Miami loam soils received 300 lbs/acre of 5-20-0 and Oshtemo sandy loam soils received 350 lbs of 5-20-0 on an acre basis.

Metal pans, 14 inches square and 2 inches in depth, were placed at the bottom of the tile. This permitted watering the containers from the bottom as well as the top. Bouyoucos moisture blocks were placed at various depths in the containers. Moisture readings were then taken weekly to insure adequate amounts of available soil moisture during the growth of the crops.

Rb as RbCl was added to a 2 inch soil layer in both Miami and Oshtemo soils at the rate of 100 ppm Rb. The Rb and soil were thoroughly mixed, moistened and permitted to air dry before placing in the glazed tile containers. Attoe (3) has shown that some soils fertilized with potassium, will fix potassium upon drying and subsequently slowly release

potassium to the available form. Therefore, the purpose of air drying the soil "fertilized" with Rb was to bring about a fixation of the Rb.

The depth of placement in the tile of the constant rate of Rb was 6-8, 10-12, 14-16 and 20-22 inches. Each treatment was replicated 3 times.

To compare uptake of Rb by plant roots with absorption of $P^{32}$, mono-ammonium phosphate labeled with $P^{32}$ was mixed with soil and placed in tiles separate from the Rb treatment of both Miami and Oshtemo soil, but at the same depths as Rb. Labeled monammonium phosphate was added to the 2 inch soil layer at the rate of 150 ppm $P_2O_5$. The source and activity of material is explained in part 2 section B of Chapter III.

Corn was used as the crop for this experiment because (1) it is a rapid growing crop with an extensive root system and (2) field studies would include the use of corn as an indicator crop. Twelve seeds of corn were planted in each container during the second week of April. At the first sampling, each container was thinned to 7 plants. Whole corn plants were sampled once a week through 8 sampling dates.

(3) Methods of analysis

Laboratory analysis of both the Miami loam and Oshtemo sandy loam soils were made with respect to pH, available phosphorus, and cation exchange capacity prior to tracer or fertilizer treatment.

TABLE I

SEVERAL CHEMICAL PROPERTIES OF MIAMI LOAM AND OSHTEMO SANDY LOAM

| Soil Material Layer of Soil Sampled - inches | Cation Exchange Capacity me/100gms | Available Phosphorus lbs/acre | pH |
|---|---|---|---|
| | Miami Loam | | |
| 0-6 | 8.50 | 120.00 | 6.5 |
| 6-12 | 7.50 | 162.50 | 6.2 |
| 12-18 | 8.13 | 30.00 | 5.3 |
| 18-24 | 12.25 | 60.00 | 5.8 |
| | Oshtemo Sandy Loam | | |
| 0-6 | 6.61 | 22.50 | 6.2 |
| 6-12 | 6.32 | 27.50 | 7.1 |
| 12-18 | 8.26 | 38.50 | 7.3 |
| 18-24 | 7.88 | 57.40 | 7.3 |

Available phosphorus was extracted from the soil with a solution that was 0.025 N with respect to HCl and 0.03 N with respect to $NH_4F$ (Bray $P_1$ test). With this procedure a soil to solution ratio of 1:25 was used. The colorimetric method of Bray and Kurtz (15) was used to determine the concontration of phosphorus that was extracted.

The cation exchange capacities of soils were determined according to the method of Richards (57). This procedure requires 4 to 6 grams of soil, depending on the soil texture, to be leached with sodium acetate. The leaching serves the dual purpose of removing the cations already present on the exchange complex and at the same time saturating the cation exchange sites with sodium. This exchangeable sodium was then removed with IN neutral ammonium acetate. The resulting solution was then analyzed for sodium with the Beckman DU Spectrophotometer equipped with a flame attachment. Adjustments for the Beckmen DU Spectrophotometer were as follows: wave length, 589; blue filter; #2 phototube resistor; 0.1 selector; 0.02 slit width; photomultiplier sensitivity of 2 and 1.0 photomultiplier zero depression.

Corn samples for plant analysis were dried at 65°C and ground in a Wiley Mill. Samples to be analyzed for Rb were extracted with a solution which was 2N with respect to ammonium acetate and .2N with respect to magnesium acetate according to the method suggested by Attoe (4). Quantitative determinations of Rb were then made with the Beckman DU flame photometer using adjustments of 783 wavelength, red filter, #1 phototube resistor, 0.1 selector, slit width of 0.095, full sensitivity with the photomultiplier and 1.0 zero suppression.

Samples to be used for the analysis of phosphorus activity were harvested and dried as described above. Samples were then weighed out and made into "infinitely thick" briquets for the quantitative determination of the $P^{32}$ activity. This method, proposed by Mackenzie and Dean (42), eliminates time consuming chemical precipitations and separations. According to the authors of this technique, the same degree of precision as in the precipitation technique is maintained.

Activity of the compressed plant samples was then determined with a Geiger-Muller counter tube and decade scaler. The amount of radioactive phosphorus in the sample was then calculated according to the method of Kristjanson, Dion, and Spinks (34).

Root weights were determined for the corn after the final crop had been harvested. The soil from each container was divided into 4, six inch sections, the soil washed away and roots collected, dried and weighed. Root weight data are presented in Table IX in the appendix.

(4) Results and discussion

Comparison of the uptake by corn roots of Rb and labeled phosphorus from various depths of two soil materials can be made in Figures I through IV.

In Figure I the uptake of the two tracers by corn is graphically presented for the treatment when the tracers were placed at the 6-8 inch soil depth. Plant absorption of the tracer materials from Miami loam followed a very similar pattern with each date of sampling. The data indicate that maximum amounts were absorbed by the fourth week after planting. Thereafter, a sharp decline in absorption occurred with both tracers following the same trend.

Although absorption of the tracers from the Oshtemo soil followed the same general trend, Rb was not absorbed in quantities comparable to those absorbed from the Miami soil. Less Rb was absorbed from the Oshtemo soil than was

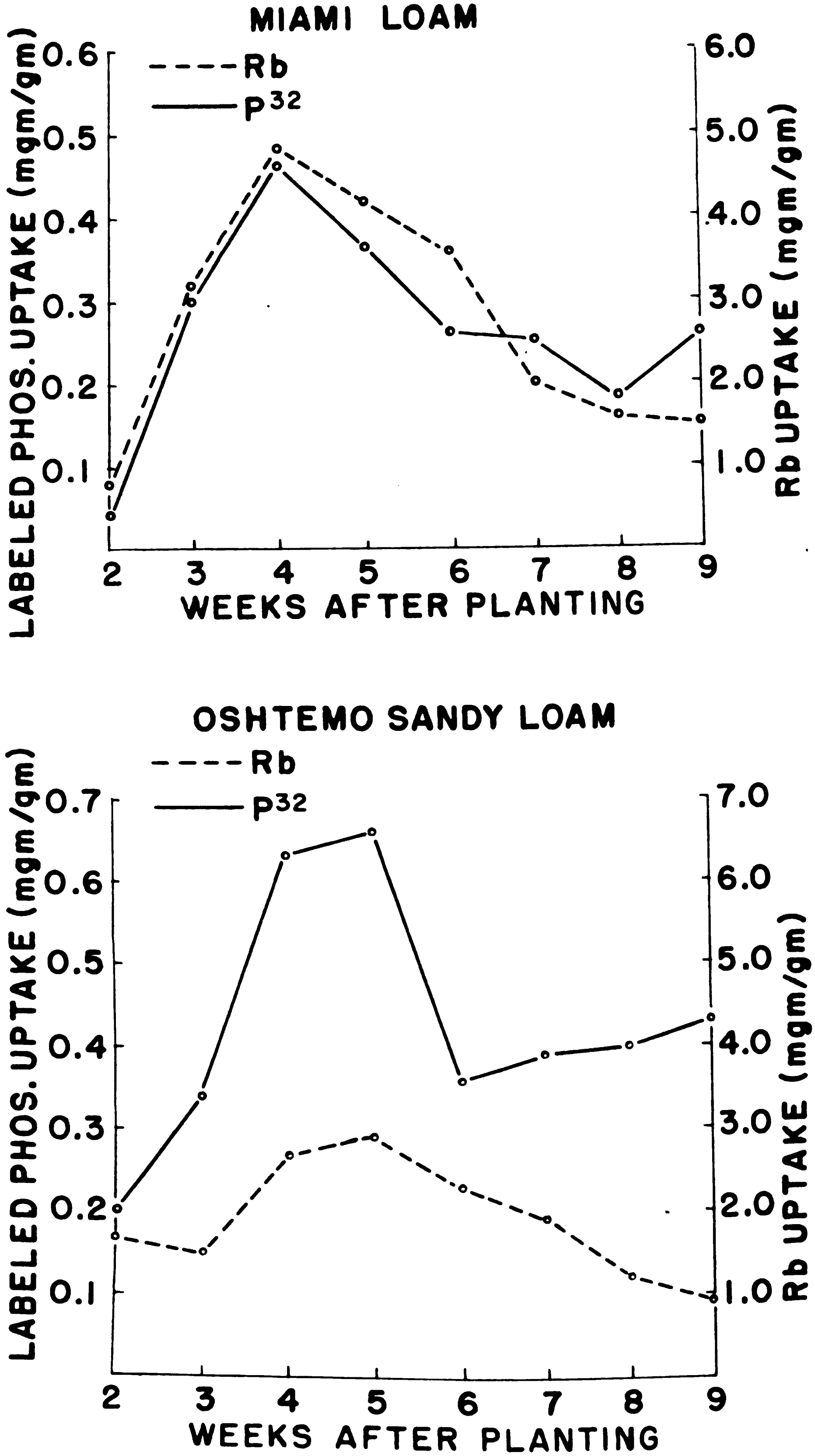



Figure I. Absorption of Rb and P32 from a 6 - 8 inch soil depth by corn at various stages of growth.

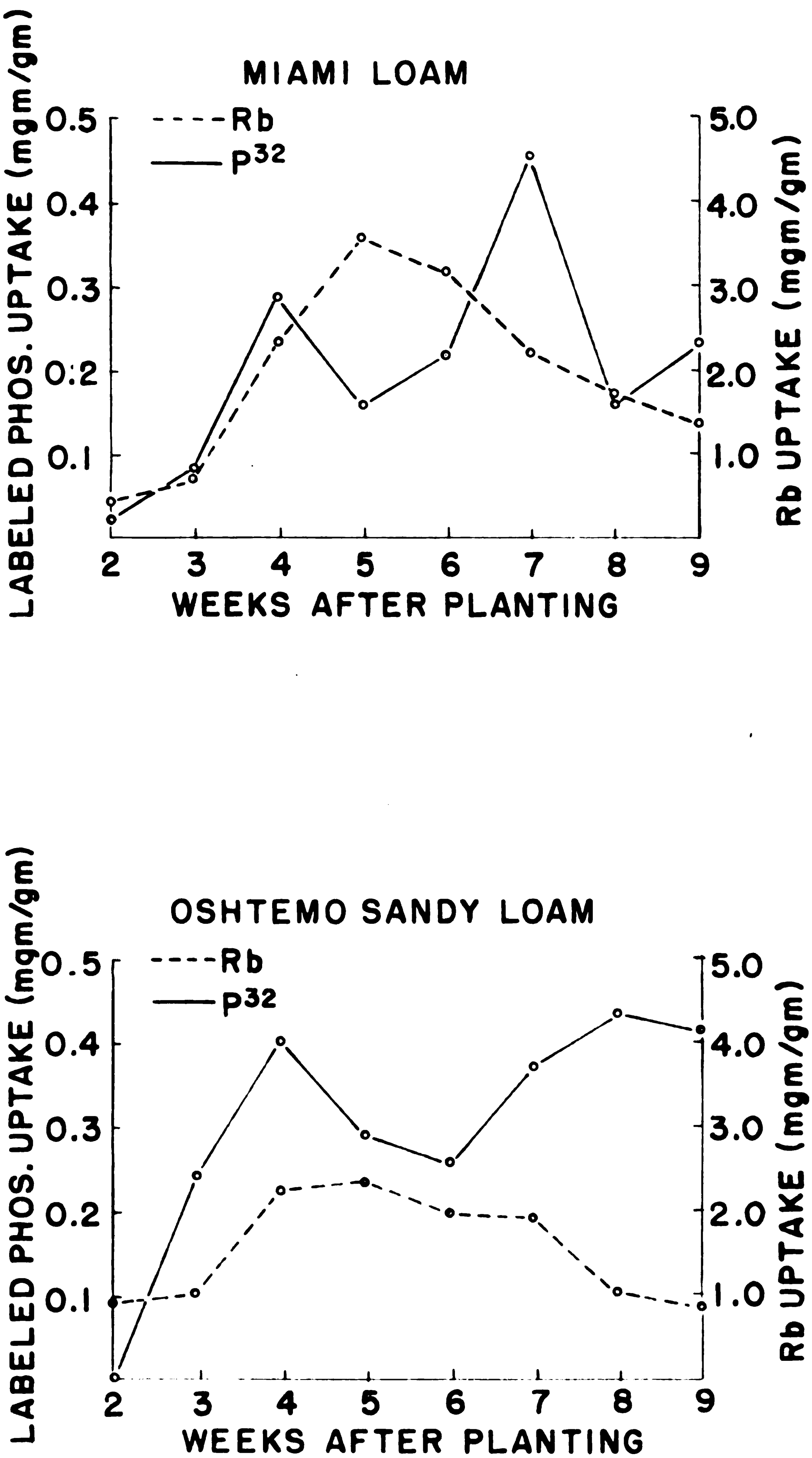
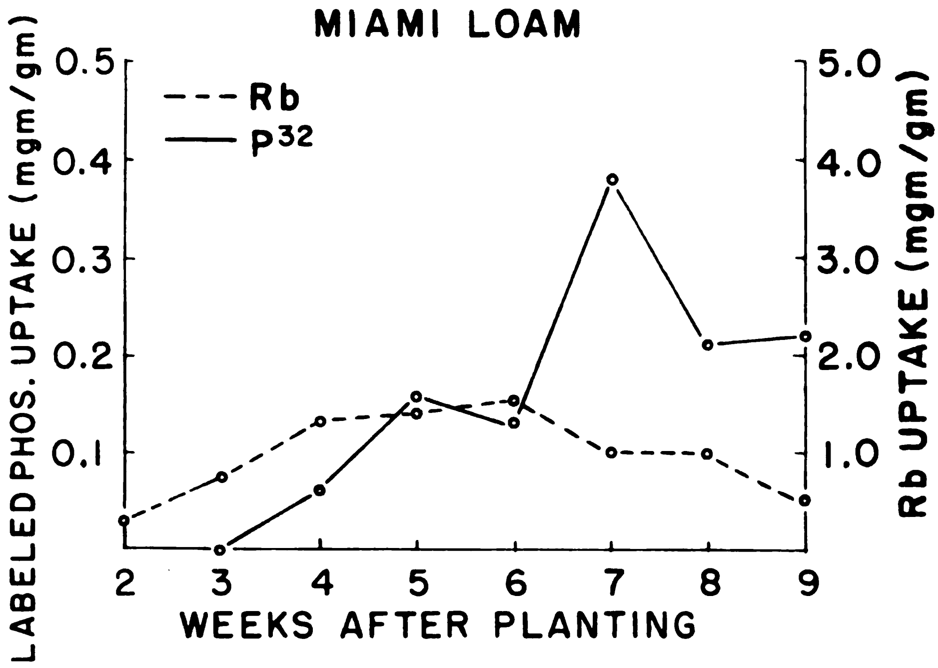



Figure II. Absorption of Rb and $P^{32}$ from a 10 - 12 inch soil depth by corn at various stages of growth.



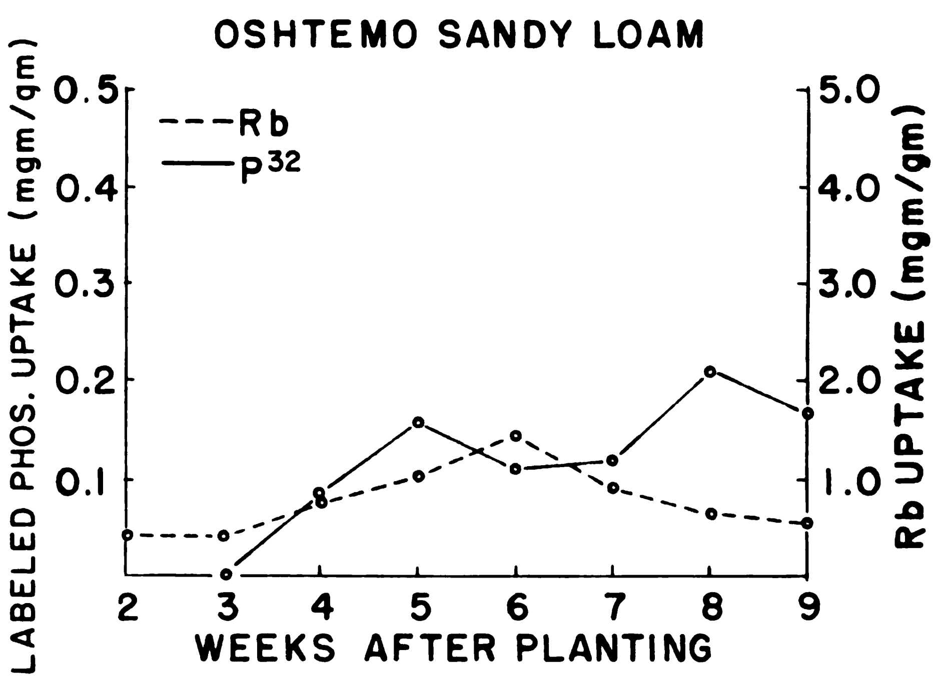
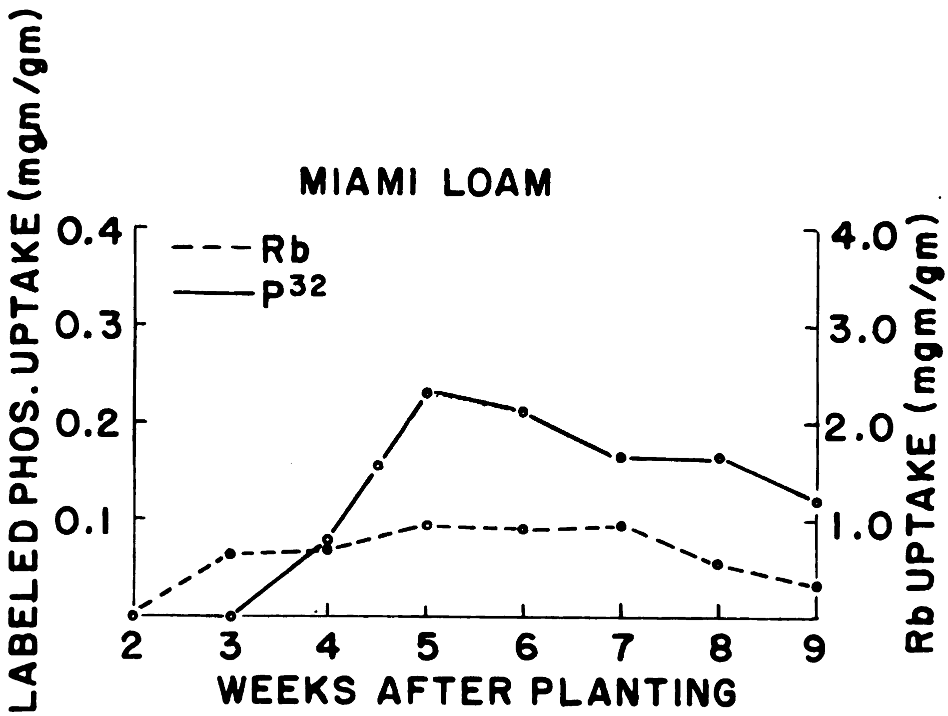




Figure III. Absorption of Rb and $P^{32}$ from a 14-16 inch soil depth by corn at various stages of growth.



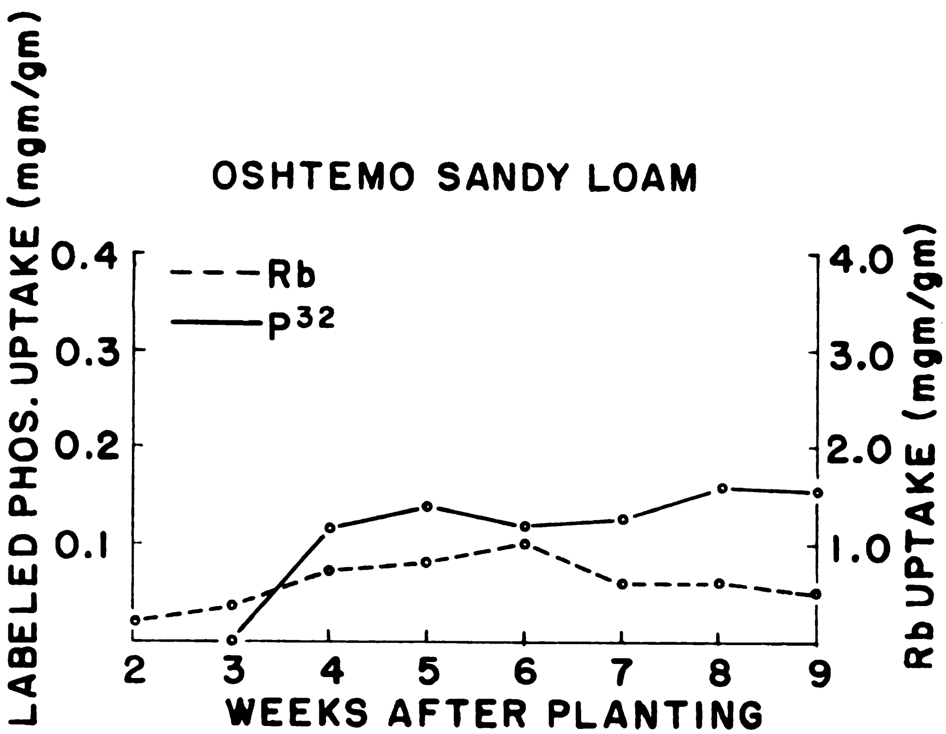




Figure IV. Absorption of Rb and $P^{32}$ from a 20-22 inch soil depth by corn at various stages of growth.

absorbed from the Miami soil at all depths of placement.

Uptake of labeled phosphorus was greater from the Oshtemo soil. According to soil analysis, the Miami soil contained considerably larger quantities of available soil phosphorus than did the Oshtemo soil. It can also be seen in Figure I that maximum absorption of the two tracer materials did not occur until the fifth sampling date from the Oshtemo soil.

On this basis, after adding labeled phosphorus to the given layers, it is reasonable to assume that of the total percent available phosphorus in the treated layer, a larger percent of labeled phosphorus would be in the available form in the Oshtemo soil. Another possible explanation for the greater uptake of labeled phosphorus from the Oshtemo soil would be that a greater fixation of labelled phosphorus occurred in the Miami soil.

A possible explanation is that some of the Rb may have been removed from the 6 - 8 inch soil zone and leached to lower depths in the soil container. Considerably more Rb was absorbed by roots from the 6 - 8 inch zone in the Miami soil. This indicates that more Rb was bound by exchange sites in the Miami soil and/or Rb fixation occurred in the 2 inch zone and this fixed Rb was subsequently slowly released.

Data presented in Figures II through IV show that uptake of the tracer materials occurred from the lower depths in the soil. In these cases the general trend of absorption of tracers by roots was similar to that described in Figure I for the 6-8 inch placement. However, maximum absorption of the tracers occurred at later sampling dates (depending on depth of placement) than was true for the placement of tracers close to the soil surface.

Figure V shows that root weights from the 2 soils followed the same trend according to depth in the containers.

Rubidium has been considered as a possible substitute for potassium in the study of soil-plant relationships. The ionic radius and the outer electron configuration of Rb and K are quite similar and this reflects on their similar chemical behavior in soils. For instance, Page and Baver (50) have shown that Rb is fixed by soil colloids in quantities similar to potassium.

According to Epstein and Hagen (24), Rb and K use the same cation absorption site of the outer protoplasmic membrane of plant cells. Since the plant cell has no preference between the two ions in its selective cation uptake, it was believed that proportionate quantities of the two ions would be taken up according to their respective concentration in the ambient solution.

A study was conducted in Ohio by Murphy, Hunter, and Pratt (49) to determine the effect of various ratios of K to Rb in the soil upon plant growth. These authors concluded that the percent recovery of Rb by the corn plant from three soils was inversely related to the available K in the soil.

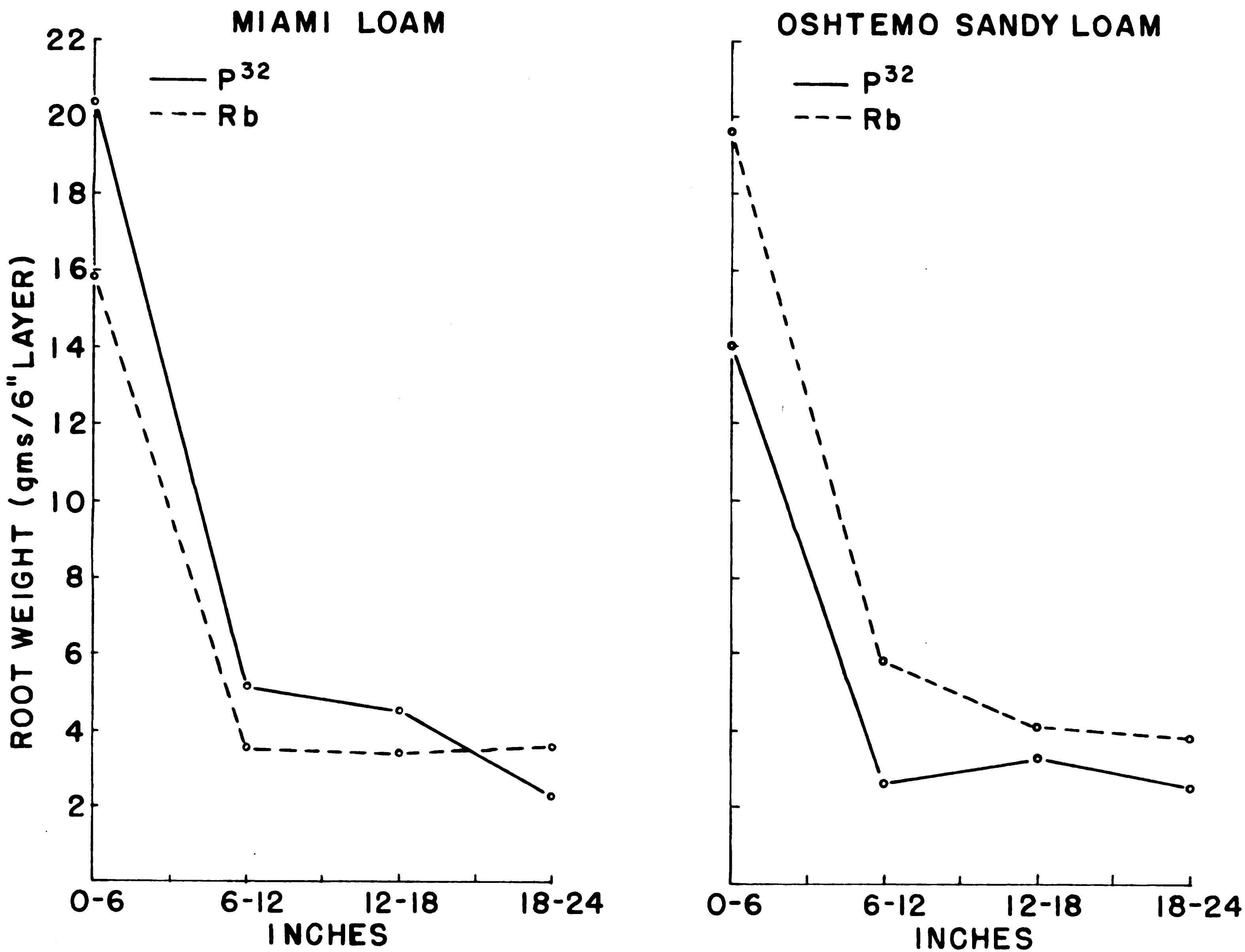



Figure V. Root weights of corn according to 6 inch depths in greenhouse studies with tracers.

From the data and information in the literature, it appears that nonradioactive Rb should be considered further as a tracer for root studies. However, a more complete understanding of the Rb - K relationship in soils is of prime importance.

B. The Use of Tracer Techniques to Study the Rooting Pattern of Several Crops in the Field.

(1) <u>Purpose</u>

A more thorough knowledge of the rooting patterns of crops with respect to the soil type on which they are growing is desired. Information of this nature would aid considerably in such matters as, variety selection, placement of fertilizers, tillage methods, and soil test evaluations. Therefore, it was believed that a field study, preliminary in nature, using tracer techniques, might help in a study of the root patterns of several crops. An attempt was also made to compare the uptake of radioactive phosphorus by corn with root weights taken at the same time.

(2) <u>Methods of procedure</u>

Two separate field studies were conducted in an attempt to evaluate the tracer technique for a study of root patterns.

One location was at the Ferden Farm, Saginaw County, Michigan, while the second site was selected on one of the Michigan State University farms at East Lansing, Michigan.

The soil type at the Ferden Farm, where investigations were carried out on the root patterns of sugar beets, is a Sims clay loam soil.

The tracer used in this study was $P^{32}$. Radioactive phosphorus was supplied to the Department of Soil Science, Michigan State University by the Agricultural Research Service, U.S.D.A., Beltsville, Maryland. The carrier of $P^{32}$ was monoammonium phosphate with a specific activity of o.15 m.c./gm. $P_2O_5$. Solutions for injection were prepared by utilizing the maximum solubility of monoammonium phosphate in water. That is, approximately 22.0 gms of the chemical compound were dissolved in 100 mls. of water. Solutions to be used for injection into the soil were all taken from the same initially prepared solution in order that all points of injection for a given location received the same activity.

The solution containing the $P^{32}$ was injected into the various predetermined points of the soil using a stainless steel probe of the type used by Murdock and Engelbert (48). This probe had a 1/8-inch outside diameter and 1/32-inch inside diameter. The probes were made of various lengths of tubing but generally were 30 inches in length. A solid, pointed tip was welded to the lower end of the probe, and immediately in back of this solid tip were two holes through the tubing at right angles to each other. These holes permitted the even distribution of the liquid at the point of injection.

The top end of the probe was welded to a leur-lok fitting from No. 16 gauge syringe needles. To apply the solution in the field, the probe was pushed into the soil to the desired depth and then pulled back $\frac{1}{2}$-inch. The glass syringe was filled with 10 c.c. of the $P^{32}$ solution, then fitted on the leur-lok on the end of the probe. The plunger in the glass syringe was then slowly depressed injecting the solution into the soil.

The distribution pattern of the labeled solution in the soil was determined by injecting India ink into the soil. Then by digging along the probe to the point where the ink was deposited in the soil the general pattern of solution distribution could be examined. The general pattern of distribution of the solution was elliptical in form and measured approximately 3 inches horizontally by 4 inches vertically.

Treatments were designed so that the placement of $P^{32}$ would be at distinct distances from and at depths below the plants under investigation. For sugar beets grown on the Sims clay loam $P^{32}$ was placed 6 and 12 inches to the side of the plants and at 6 inch intervals to a depth of 18 inches below the plants. For corn grown on the Macomb sandy loam, side placements of the tracer were located at 6 inch intervals up to 18 inches away from and below the plants. One treatment with corn extended to a depth of 30 inches.

Treatments were placed in the field on corn plots when the corn was 6 to 8 inches high (approximately 4 weeks after seeding). Treatments for sugar beets were established immediately following blocking and thinning of the beets. There were 26 injections per treatment, that is, 13 injections on both sides of the row and each injection 10 inches apart.

(3) Methods of analysis

Some of the important chemical characteristics of this soil are listed in Table II.

TABLE II

SEVERAL CHEMICAL PROPERTIES OF SIMS CLAY LOAM AND MACOMB SANDY LOAM

| Soil Type | Depth of Sampling inches | Cation Exchange Capacity me/100gms | Available Phosphorus lbs/acre | pH |
|---|---|---|---|---|
| Sims Clay Loam | 4-8 | 23.75 | 116.0 | 5.8 |
| | 10-14 | 15.50 | 10.0 | 6.2 |
| | 16-20 | 20.00 | 0.50 | 6.4 |
| Macomb Sandy Loam | 4-8 | 8.87 | 37.50 | 6.9 |
| | 10-14 | 7.89 | 6.00 | 6.9 |
| | 16-20 | 4.89 | 0.00 | 7.2 |

The second study, which was conducted on the University farm, was carried out on a Macomb sandy loam soil. The crop studied at this site was corn and a partial chemical analysis of this soil is reported in Table II.

All chemical determinations of these two soils were performed according to the procedures already described in section (3), Part A of Chapter III.

For analysis of labeled phosphorus absorbed by plants, samples of the third functional leaf from the bottom of the corn plant and sugar beet leaves intermediate in age were collected. Leaf samples from both corn and sugar beets were taken when the plants were at 6, 8, 10 and 12 weeks of age.

All plant materials were dried, ground, made into briquets and activity counts determined as described in section (3) Part A of Chapter III. The data are presented in Tables X and XI in the appendix.

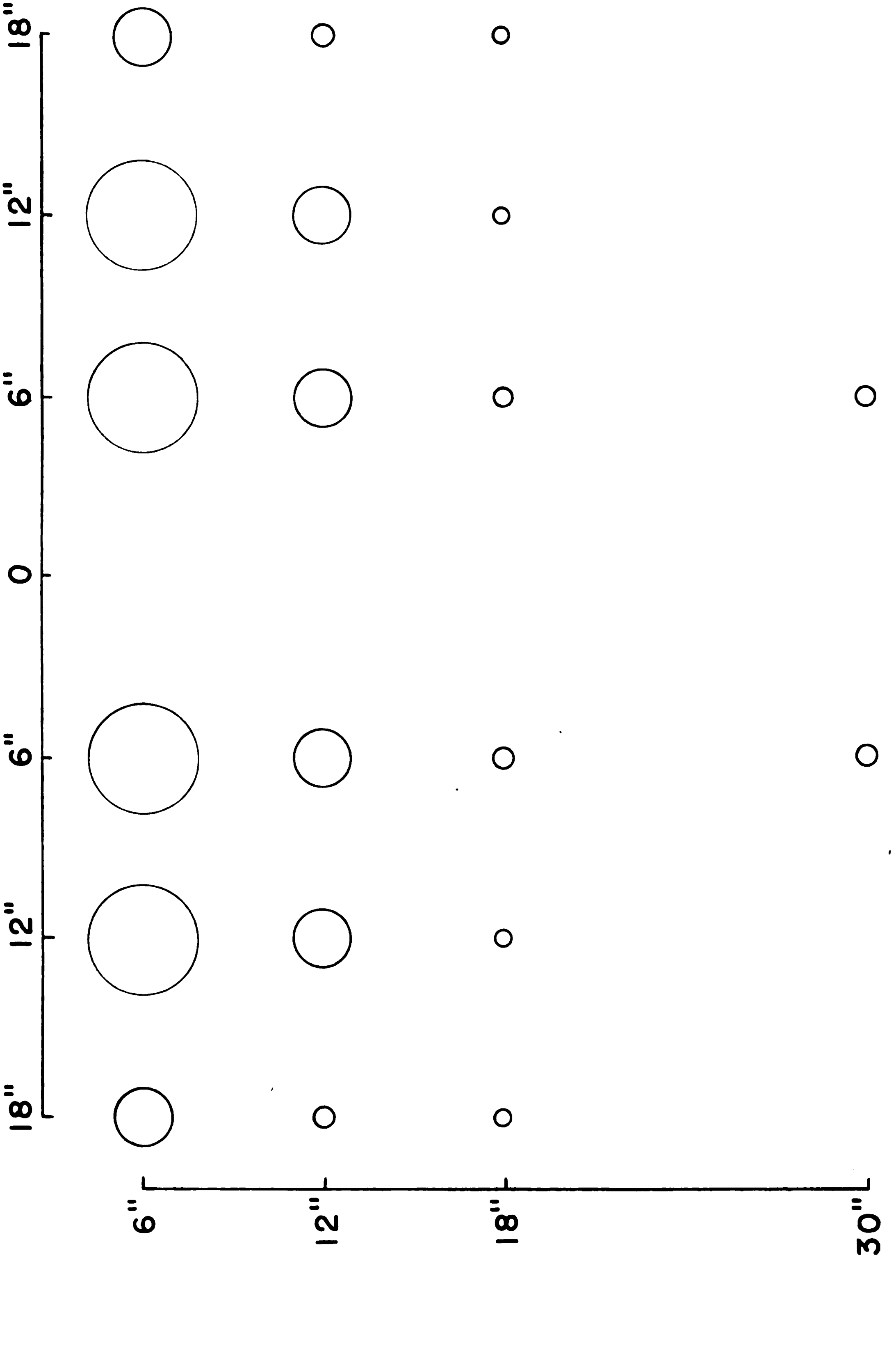
Root samples were taken from the corn plots each time the plant tissue was sampled. This was done by digging a trench along the side of the corn row. The wall of the trench adajacent to the corn row was 3 inches distant from the center of the row.

Blocks of soil containing roots were removed from the inside wall of the trench by forcing sampling boxes into the soil by means of a hydraulic jack. These sampling boxes, made of metal, were 5 inches square and 6 inches deep. Root samples were taken at positions in the soil representing similar points where $P^{32}$ had been injected with respect to distance away from and depth below the plant. Immediately thereafter the soil blocks were soaked in water with a detergent overnight and the soil was washed away from the roots the following day. The roots separated by this procedure were then dried and weighed. Root weights according to sampling date and position in the soil sampled are presented in Table XII in the appendix.

(4) Results and discussion

The root patterns of corn plants according to root weights and the activity of leaves based on $P^{32}$ absorption, are presented graphically in Figures VI through VIII. Only data from 3 of the 4 sampling dates are presented in graphic form. From the several figures, comparisons can be made between the actual dry weights of roots and data based on the absorption of $P^{32}$ by corn leaves. From Figure VI it is evident that at the first sampling the majority of roots and most of the root activity both occur within the 0 to 6 inch depth of soil extending out 12 inches on either side of the plant. At this stage of growth only very small amounts of roots were found at the other positions in the soil according to the two techniques. According to absorption of labeled phosphorus, a few roots had extended to a position 18 inches away from and 18 inches below the plant. However, no roots were found at this position by the recovery procedure used.

The patterns of root growth and root activity at the 10 week growth stage (Figure VII) show striking similarities between root development and root activity. However, $P^{32}$ absorption indicated greater relative activity in the 18 inch depths at the sides of the corn plant. In comparing most development after 10 weeks with that after 6 weeks, great differences can be seen. At the 10 weeks growth stage, a large concentration of roots had developed directly below the plant and a considerable increase in root growth and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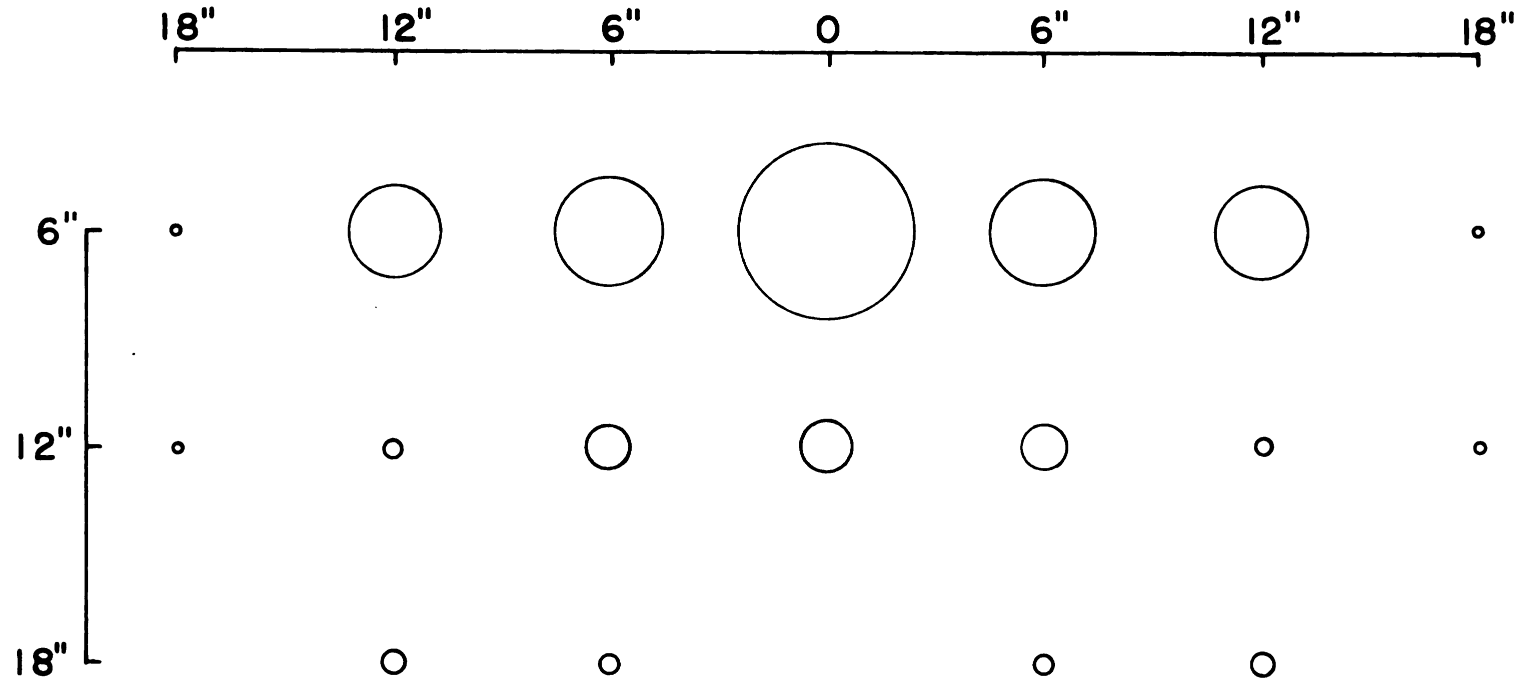
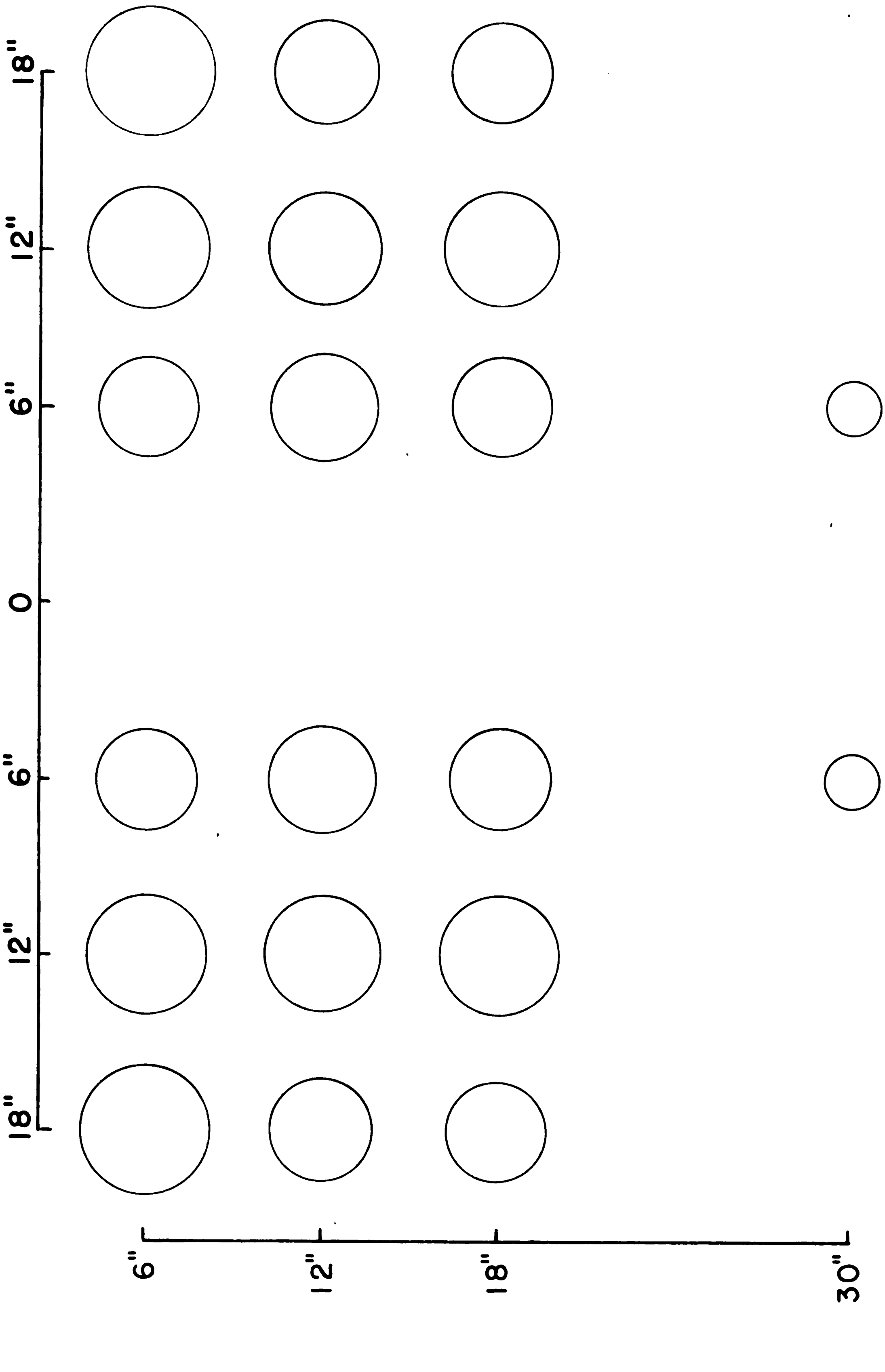



Figure VI. Comparison of actual root weights (lower graph) with absorption of labeled phosphorus (upper graph) at different positions in the soil by corn at six weeks of growth. (Areas within circles represent actual values given in Tables XI and XII). The horizontal and vertical lines represent soil surface and soil depth respectively. The "O" indicates position of plant.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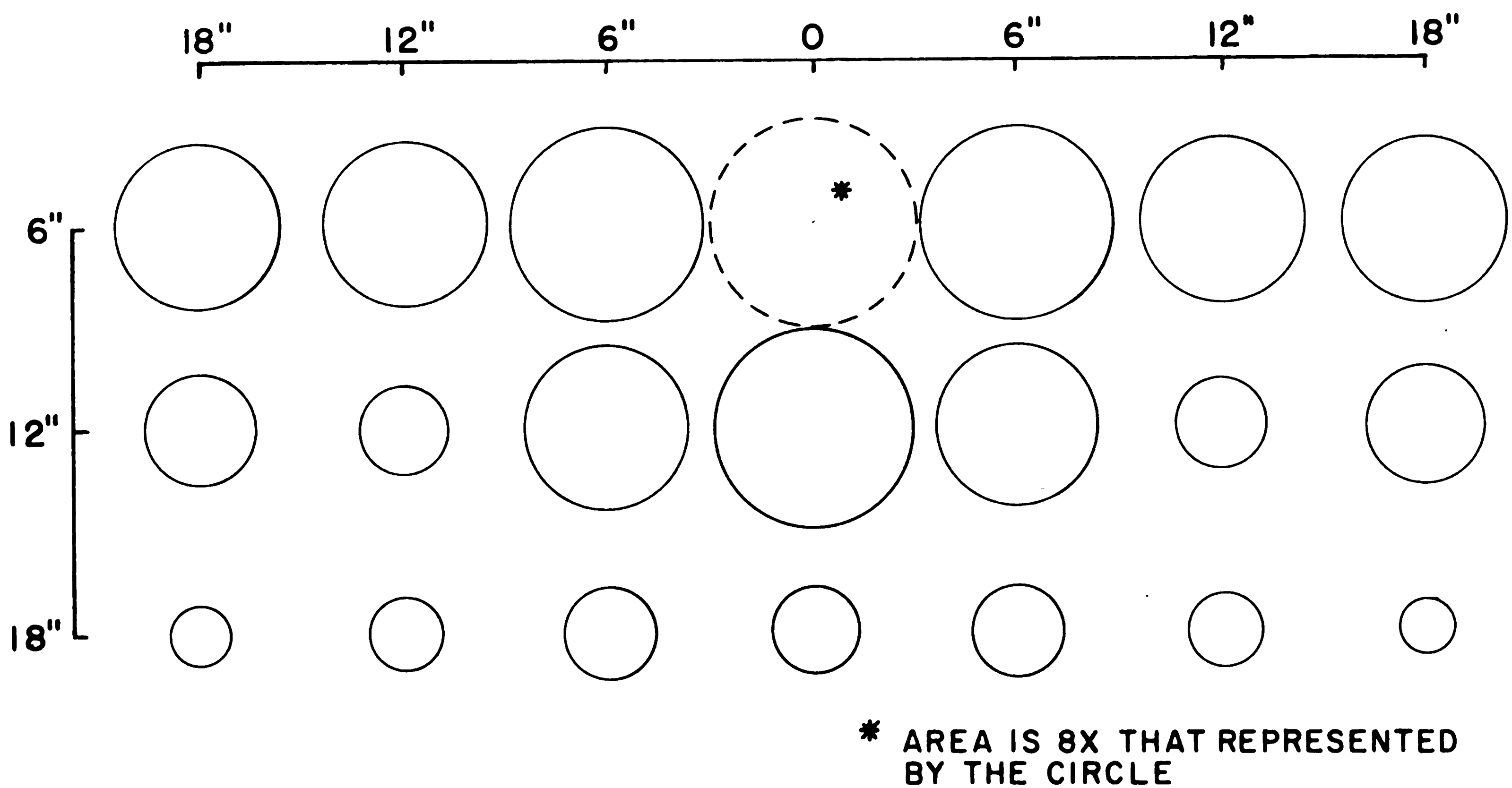
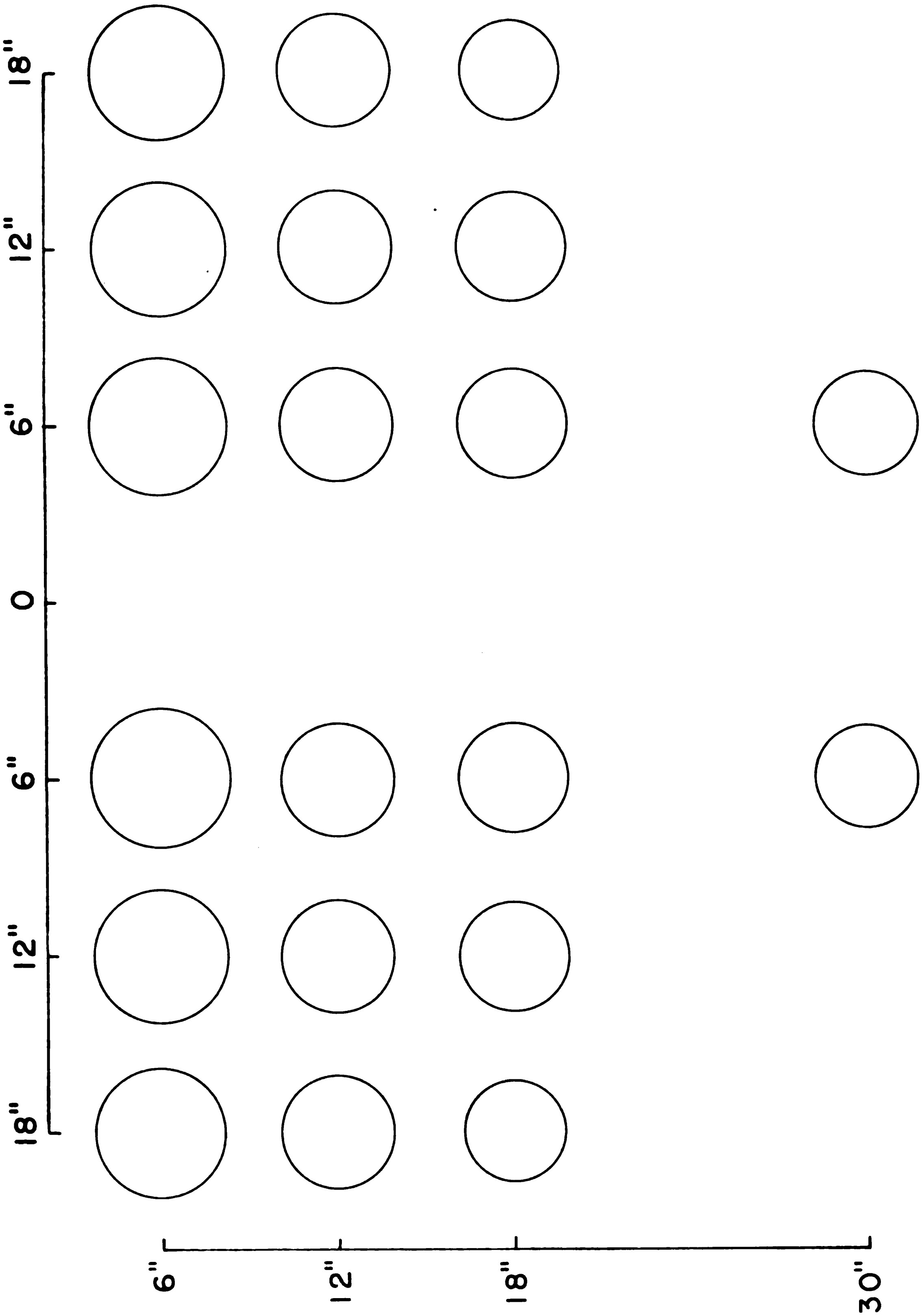



Figure VII. Comparison of actual root weights (lower graph) with absorption of labeled phosphorus (upper graph) at different positions in the soil by corn at ten weeks of growth. (Areas within circles represent actual values given in Tables XI and XII). The horizontal and vertical lines represent soil surface and soil depth respectively. The "O" indicates position of plant.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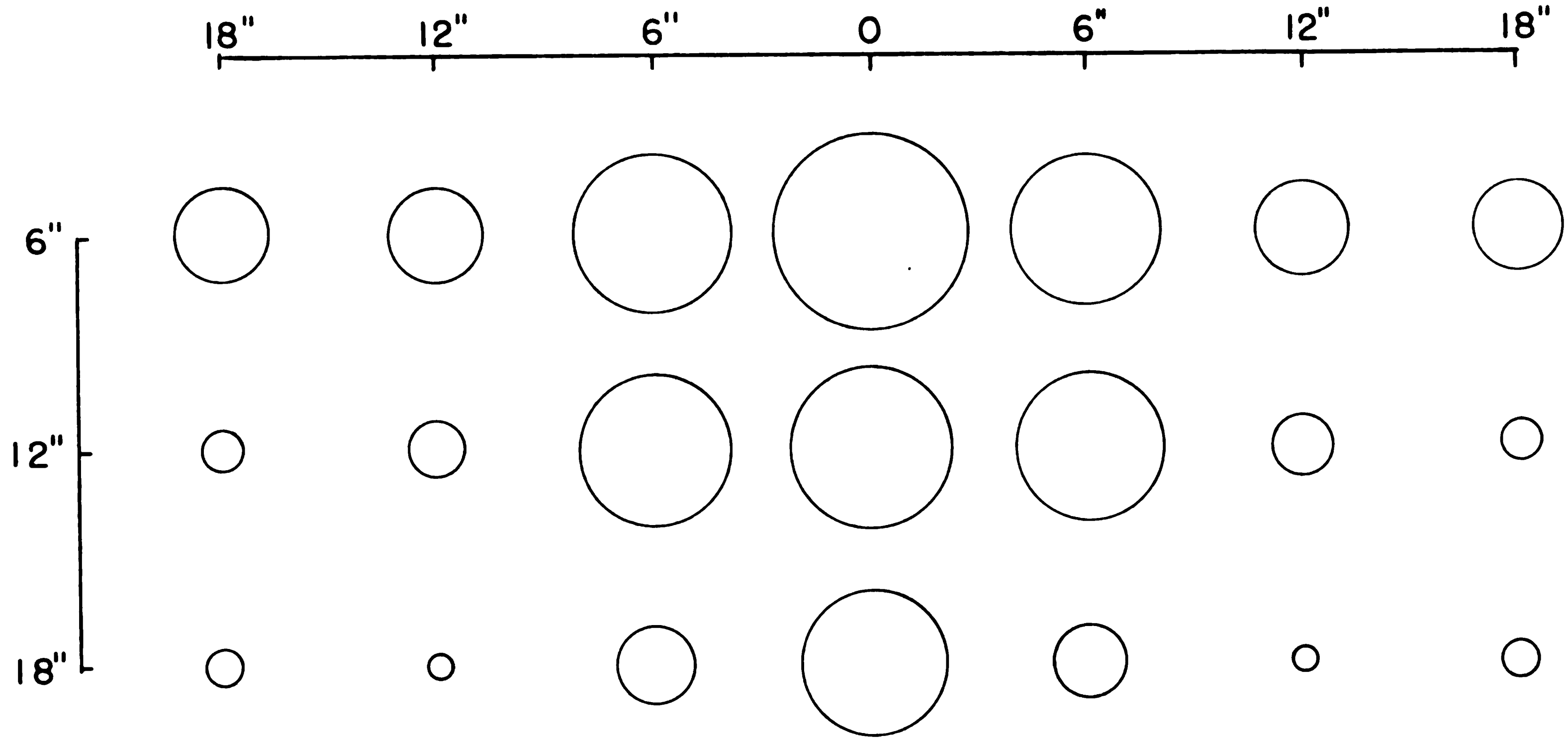



Figure VIII. Comparison of actual root weights (lower graph) with absorption of labeled phosphorus (upper graph) at different positions in the soil by corn at twelve weeks of growth. (Areas within circles represent actual values given in Tables XI and XII). The horizontal and vertical lines represent soil surface and soil depth respectively. The "O" indicates position of plant.

activity was evident at all 3 depths 18 inches to the side of the plant.

The root activity exhibited by data presented in Figure VIII illustrates the rather large volume of soil occupied by plant roots of mature corn. It is apparent that the heavier concentrations of roots were found at the 6 inch depth extending to 18 inches on either side of the plant and directly below the plant extending to a depth of 18 inches.

According to data from the uptake of labeled phosphorus at 12 weeks of growth, the corn roots in the volume of soil studied had a relative uniform activity with respect to absorption of $P^{32}$

It should be pointed out that $P^{32}$ was placed at the 30 inch depth in only one treatment. The subsoil was so dense it caused the injection probes to bend and no further placement at the 30 inch depth was attempted.

In comparing root activity with actual root weights, for 4 sampling dates, the trend is quite similar. However, the data indicate that high root activity is not necessarily accompanied by high values for root weights.

Corn root weights at the 12 week stage of growth were considerably less than at previous sampling dates. A possible explanation would be that errors in sampling and/or dry soil conditions brought about a reduction in root weights.

Differences in sugar beet root activity based on uptake of labeled phosphorus can be seen in Figure IX. From

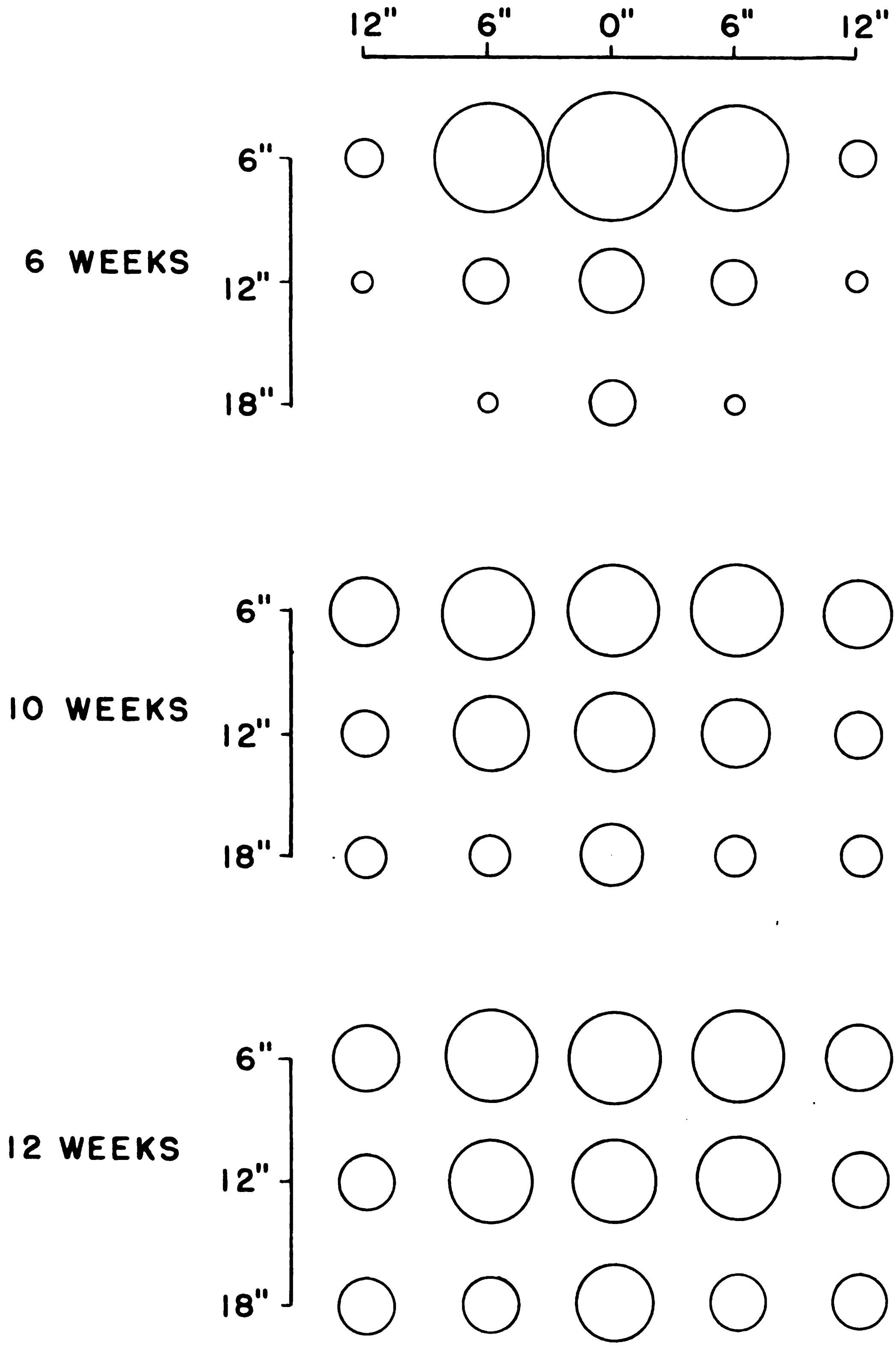



Figure IX. Sugar beet root activity in Sims clay loam as measured by $P^{32}$ absorption. The horizontal and vertical lines represent soil surface and soil depth respectively.

these data, comparisons of root activity can be made with respect to distance away from and below the plant and the age of the plant.

For beet plants 6 weeks old, maximum active root development occurred in a volume of soil 6 inches deep and 6 inches on either side of the plant. After 10 weeks of growth, the actively absorbing beet roots had extended to a depth of 18 inches directly below the plant and from 6 inches on either side of the plant to a depth of 12 inches.

Two weeks later, the majority of the roots were concentrated in approximately the same volume of soil as at the 10 week sampling period. However, the absorption of labeled phosphorus by the plants at that stage of growth did indicate that activity of roots was considerably greater 12 inches away from the plant at the 6, 12 and 18 inch depths.

# IV. EVALUATION OF THE EFFECTS OF PHYSICAL SOIL PROPERTIES ON ROOT GROWTH AND DEVELOPMENT

## A. The Effect of Compaction on Root Growth

### (1) Purpose

This study was conducted under green house conditions to investigate the effect of compaction on the vertical distribution of roots.

### (2) Methods of procedure

The soil for this study was a Sims clay loam obtained from the Ferden Farm, Saginaw County, Michigan. The soil was collected at 6 inch increments down to a depth of 24 inches. These respective soils were then air dried, screened, and placed in glazed drain tile in 6 inch increments representative of the occurrence of the layers under natural field conditions.

The use of metal pans under the tile and Bouyoucos moisture blocks in the soil is the same as that described in section (3), Part A of Chapter III.

Optimum amounts of nitrogen, phosphorus, and potash were provided in the surface five inches of each container, as previously described in section (2), Part A of Chapter III.

A total of 8 treatments were used and each treatment was replicated 3 times. The treatments are given in Table IV. Monoammonium phosphate containing labeled phosphorus was added to the 2 inch soil layers at the rate of 150 ppm $P_2O_5$.

Compaction of 2 inch soil zones was accomplished by taking a given quantity of soil and placing it in a pail. Water was added to the soil until a thick paste was formed. Constant stirring essentially destroyed the soil structure. The puddled soil was then placed at the desired depth in the tile and packed into place by tamping the soil with a heavy object. Bulk densities of the compacted layers were 1.38 at the 6-10 inch depth and 1.46 at the 16-20 inch depth. The non compacted layers had bulk densities ranging from 1.12 to 1.20.

Corn was selected as the indicator crop. Planting and harvesting of the corn was accomplished in the same manner as described in section (2), Part A of Chapter III.

(3) Methods of analysis

Laboratory analysis was performed on the 4 soil layers with respect to pH, cation exchange capacity, and available phosphorus.

Analytical procedures were used as described in section (3), Part A of Chapter III. Results of the soil chemical analysis are presented in Table II.

Plant analysis for phosphorus activity was the same as that described in section (3), Part A of Chapter III. Root weights were also determined as described previously in the same section.

(4) Results and discussion

The results of this study are given in Table III.

In comparing the compacted with the noncompacted treatments at the 6-10 inch depth, the data indicate that a possible retardation of vertical root movement occurred due to compaction. It can be noted that considerably more $P^{32}$ was taken up from the soil layer immediately above the compacted zone than from the same layer where no compaction occurred. This possibily was caused by roots being retarded in their downward penetration of the soil.

TABLE III

LABELED PHOSPHORUS IN CORN AS EFFECTED BY PLACEMENT OF $P^{32}$ AND COMPACTION AT VARIOUS DEPTHS

| Placement $P^{32}$ inches below surface | Compaction inches below surface | Sampling Dates - Weeks After Planting (mgms labeled phos./gm plant material) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 4-6 | none | 0.259 | 0.204 | 0.526 | 0.805 | 0.905 | 0.549 | .0381 | 0.469 |
| 4-6 | 6-10 | 0.594 | 1.175 | 1.000 | 0.687 | 0.718 | 0.377 | 0.349 | 0.337 |
| 10-12 | none | 0.000 | 0.078 | 0.278 | 0.519 | 0.414 | 0.270 | 0.377 | 0.319 |
| 10-12 | 6-10 | 0.008 | 0.000 | 0.226 | 0.311 | 0.371 | 0.193 | 0.361 | 0.341 |
| 14-16 | none | 0.000 | 0.002 | 0.421 | 0.276 | 0.191 | 0.152 | 0.271 | 0.396 |
| 14-16 | 16-20 | 0.000 | 0.000 | 0.109 | 0.308 | 0.373 | 0.432 | 0.303 | 0.314 |
| 20-22 | none | 0.000 | 0.003 | 0.006 | 0.306 | 0.141 | 0.363 | 0.226 | 0.245 |
| 20-22 | 16-20 | 0.000 | 0.000 | 0.038 | 0.077 | 0.115 | 0.094 | 0.171 | 0.210 |

Thus, considerably more $P^{32}$ was absorbed above the zone of compaction in comparison with uncompacted treatments.

In the situation where $P^{32}$ was placed below the 6-10 inch zone of compaction, absorption of labeled phosphorus again indicated that compaction had delayed roots in their downward movement in the soil. At the third sampling date, roots were absorbing phosphorus from the 10-12 inch layer where there was no compaction at the 6-10 inch zone. When there was compaction at this depth, root development was restricted and phosphorus absorption was not evident until the fourth sampling date.

It was found that a compact layer at 16-20 inches also increased absorption of $P^{32}$ above this zone as compared with the non-compacted treatment. However, maximum absorption of phosphorus from the 14-16 inch depth was not apparent until the fifth sampling date. Absorption of phosphorus above the dense layer was considerably greater than where compaction was not included in the treatment.

Compaction at a depth of 16-20 inches with $P^{32}$ placed below the compacted zone indicated that again corn roots were retarded in their movement through the compacted layer. Considerably more phosphorus was absorbed by roots at each of the last 5 sampling dates where layers of compaction did not occur in the treatment.

Total root weights were not affected by the various treatments (Table IV).

Compaction of various depths of clay loam soils to the bulk densities used in this study did retard the downward penetration of corn roots. However, the bulk density of the 16-20 inch zone (1.46) appears to be more effective in restricting root penetration than the density of 1.38 which occurred at the 6-10 inch depth.

The data of this study indicate that compaction at the 6-10 inch depth delayed root penetration by one week. A possible explanation would be that roots in absorbing water above and in the compacted layer improved conditions of aeration permitting the roots to develop and penetrate.

TABLE IV

THE EFFECT OF COMPACTION ON THE ROOT PATTERNS OF CORN PLANTS GROWN ON A SIMS CLAY LOAM UNDER GREENHOUSE CONDITIONS

| Placement of $P^{32}$ inches below surface | Compaction inches below surface | Root Weights of Soil Layers 0-6" | 6-12" | 12-18" | 18-24" |
|---|---|---|---|---|---|
| | | | gms/6" layer | | |
| 4-6 | none | 12.8 | 1.90 | 1.50 | 1.20 |
| 4-6 | 6-10 | 14.3 | 2.7 | 1.5 | 1.0 |
| 10-12 | none | 12.7 | 0.6 | 0.4 | 0.7 |
| 10-12 | 6-10 | 7.3 | 0.8 | 1.0 | 0.5 |
| 14-16 | none | 11.0 | 0.6 | 0.5 | 0.4 |
| 14-16 | 16-20 | 19.1 | 2.3 | 2.4 | 0.8 |
| 20-22 | none | 13.1 | 1.1 | 0.7 | 0.5 |
| 20-22 | 16-20 | 12.5 | 1.3 | 1.2 | 0.4 |

## B. The Effect of Aeration and Mechanical Impedance on the Root Growth of Alfalfa, Sugar Beets and Tomatoes

### (1) Purpose

Studies have been conducted to determine the effect of dense or compact subsurface soil layers on root penetration and development. The controversial nature of the literature and lack of quantitative evidence have not solved the problem of why roots fail to develop in layers of high bulk density.

The purpose of this study was to determine if mechanical impedance or lack of aeration restricts the growth of roots in dense, unconsolidated subsurface soil layers.

(2) Methods of procedure

This study was conducted in the Plant Science Greenhouse using metal stove pipe as soil containers. Granby sand was used for layers overlying and underlying the zone of compaction. For treatments without dense layers Granby sand was used throughout the container as the medium for plant growth.

A dense layer with a bulk density of 1.95 was attained by essentially filling the voids between quartz sand particles with kaolinite and $<0.2$ mm sand. For a volume of 347.3 $cm^3$, 20 gm kaolin, 60 gm of 0.2 mm sand, and 580 gm of quartz sand were used. To reach a bulk density as high as 1.95, the weighed amounts of the materials mentioned were moistened and carefully packed into the given volume in the containers.

A thin section of this compacted layer was prepared and can be seen in Figure X. To insure that adequate amounts of nitrogen, phosphorus, and potassium were present for normal plant growth in the containers, 400 lbs, on an acre basis, of 5-20-20- fertilizer were added. This fertilizer was thoroughly mixed with all soils in the containers irrespective of compaction treatment.

Calcium peroxide was used as the source of oxygen in compacted layers having aeration. This compound is one of the most stable of the peroxide compounds. According to the manufacturers it has an active oxygen content of 13.3 percent by weight. At a relative humidity of 80 percent, the peroxide loses 11.7 percent of its active oxygen per week. Calcium peroxide is only slightly soluble in water and decomposes in the presence of the alkaline earth metals.

Amounts of oxygen released per day were determined by placing a core containing the materials of the compacted layer and peroxide in an air tight box of known volume. The measurement of oxygen in the system was accomplished by connecting an outlet of the box with a Beckman Oxygen Analyzer. Readings were taken at 24 hour intervals for 7 weeks. To insure that oxygen determinations were from the peroxide source, the entire system was flushed with nitrogen once a week. Amounts of oxygen released were calculated according to the method of Raney (56).

It was found that approximately 5 $cm^3$ of oxygen were released in a 24 hour period of time. This same rate of release was rather constant over a period of 7 weeks.

One of the problems in conducting a study of this nature was to determine the amount of calcium peroxide to use. Information from the manufacturers did not indicate how the compound would react in soil. However, according to Wiersma and Mortland (71), 4.26 grams of the peroxide was equivalent to 0.58 grams of active oxygen per cubic foot of soil. Because of the slow rate of decomposition of the peroxide, the amount of calcium peroxide per cubic foot of soil used in this study was 1.16 grams of active oxygen.

The containers used were galvanized stove pipe, 10 inches in diameter and 12 inches deep. Metal pans, 14 inches square and 2 inches deep were placed under each container. Water was kept in the pans at all times and equal amounts of water were added to the surface of the soil to insure adequate and equal amounts of moisture in all treatments. The seams along the sides of the containers were sealed with a plastic tape to prevent the exchange of gasses between the atmosphere and soil in the containers.

Stove pipe used as greenhouse containers have the distinct advantage over conventional containers in that they are easily taken apart at the seams. Thus, the roots and soil in the containers are easily accessible in an undisturbed condition for further studies.

In the design of the experiment, the 3 treatments used were as follows:

A - Granby soil occupied the entire volume of the container and there was no compacted layer in the treatment. Calcium oxide was incorporated in the 4-8 inch depth of soil.

B - A compacted layer was incorporated at the 4-8 inch depth and calcium oxide was mixed in the 4 inch zone of compaction. Four inch layers of Granby soil were placed above and below the zone of compaction.

C - A 4 inch compacted layer was placed at the 4-8 inch depth with calcium peroxide incorporated into the layer. Four inch layers of Granby sandy soil were placed above and below the compacted layer.

Calcium oxide was used in treatments not receiving $CaO_2$ with equivalent amounts of Ca to eliminate an effect due to calcium. Both calcium compounds were thoroughly mixed with the materials of the compacted zone before placing them into the containers.

Three different crops were grown on soils receiving the 3 treatments, and each treatment was replicated 4 times, which resulted in a total of 36 containers.

The crops used were alfalfa, sugar beets and tomatoes which were selected mainly on the basis of their root systems and sensitivity to oxygen in the soil. The root systems of alfalfa and sugar beets are characterized as having a tap root while the root system of the tomato is fibrous.

Alfalfa and tomato plants were seeded in greenhouse flats and transplanted to the greenhouse containers 2 weeks after germination. This procedure permitted the selection of plants having uniform top and root growth. Three plants were transplanted to each container.

Multi-germ sugar beet seed was planted in the containers. Two weeks after germination, each container was thinned to 3 plants.

(3) Methods of analysis

Weights of both tops and roots were obtained from the 3 crops. Sugar beets and tomatoes were harvested 6 weeks after planting. The dry weights of alfalfa tops and roots were determined 16 weeks after planting time since it is a slower growing crop.

Roots from the containers were obtained by opening the stove pipe along its seam and removing the core of soil. The soil core was placed on a screen made from 8X8 hardware cloth. A fine spray of water was applied. This rapidly removed the soil exposing the roots. The roots were collected according to 4 inch soil depths, dried and weighed. Since some quartz sand particles were found adhering to the roots, all root samples were ignited in a muffle furnace following the initial weighing. After ignition in the muffle furnace at 600°C, the ash was destroyed by adding HCl and water and boiling to dryness on a hot plate. The samples were then reweighed and the weight loss was attributed to actual root weights.

For tomatoes and sugar beets, total root weights were calculated for each 4 inch soil layer. However, for alfalfa the roots in the compacted zones were divided into tap and fibrous roots and weighed separately.

(4) Results and discussion

In Figure X comparisons can be made of thin sections from the compacted layer used in this study, a fragipan from a northern Michigan soil, and a normal soil layer.

A similarity can be seen in the close packing of the sand grains and clay occupying the voids between the sand grains when comparing the thin section of the fragipan and that of the compacted layer from this study. The normal soil layer, as represented by the thin section at the bottom of the page, has much wider spacings of the sand grains and soil pores are evident.

According to Yassoglou (75) fragipans in northern Michigan soils are characterized by high bulk densities (1.8 - 2.0) close packing of sand grains, and a minimum of root development within the fragipans. Root development is quite abundant in overlying layers and sometimes in underlying layers. It had been noted by Yassoglou that alfalfa tap roots had penetrated the fragipans but fibrous root development was at a minimum.

It was concluded from these comparisons that the compacted layers used in this experiment was a dense unconsolidated pan similar to wet fragipans or other dense pans found in nature.

Root weights obtained from the three soil depths in each treatment are presented in Table XIII in the appendix. All root weights were analyzed statistically.

Root weights obtained from soil containing peroxide

Figure X. Thin sections of a compacted layer, fragipan, and normal soil layer.

Upper photograph:

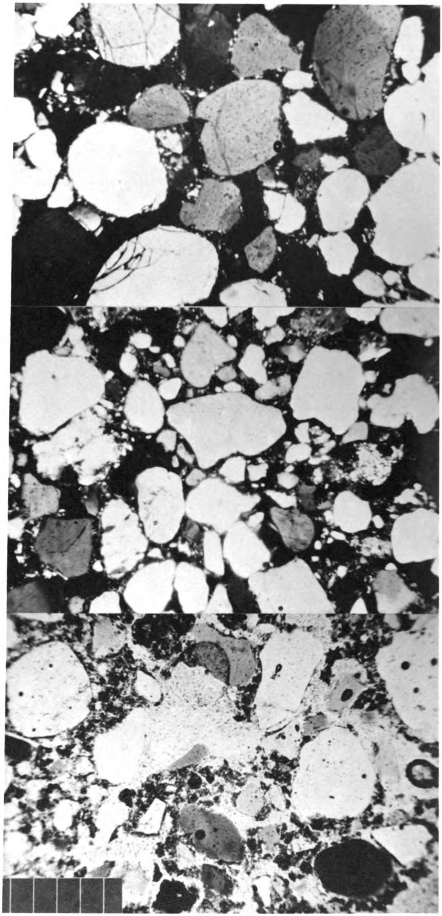
A thin section from the compacted layer as produced from quartz sand, kaolin, and <.2mm sand. Note the close packing of sand grains which are spheroidal in shape and light to gray in color. Dark areas are voids between grains filled with clay.

Middle photograph:

A thin section from a fragipan of a northern Michigan soil. Sand grains and clay are the same as described in upper photograph. (courtesy N. Yassoglou)

Lower photograph:

A thin section from a normal soil layer of a northern Michigan soil. Large light colored speriods are sand grains. Light speckled areas are soil pores. The scale in the lower left hand corner represents 100 microns for each division. (courtesy N. Yassoglou)



in the compacted layers for alfalfa were significant at the 1% level according to the F test. Statistical analysis of the weights of tap and fibrous roots of alfalfa indicated that fibrous roots were present in amounts that were highly significant in compacted layers receiving peroxide treatments as compared to compaction without peroxide. However, there was no significant difference in the weight of tap roots from compacted layers with and without peroxide.

Studentized Range Tests (22) were applied to the data and again this test indicated the significant development of alfalfa roots in the compacted zone containing peroxide. Results of statistical analysis as evaluated by these Range Tests are presented in Table V. Values for dry weights of alfalfa tops did not indicate a significant response to calcium peroxide when analyzed statistically.

In Figure XI, results of root and top weights are presented graphically by a bar graph on which root weights are compared according to depth and treatment.

Data for the 0-4 inch depth show that root weights were higher for this depth where peroxide had been incorporated in the lower layer. Apparently the source of oxygen at the 4-8 inch depth stimulated greater root development in the surface 4 inches.

In the 4-8 inch depth, root weights of alfalfa were considerably higher as a result of peroxide in the compacted layer. In this case, it is interesting to note that tap roots were not restricted in vertical growth by the compacted

TABLE V

STUDENTIZED RANGE TEST FOR WEIGHTS OF ALFALFA ROOTS

| | Alfalfa Root Weights (gm/4 inch layer) | | |
|---|---|---|---|
| | Depth(1) | | |
| Treatments | 0-4" | 4-8" | 8-12" |
| A | 2.3536 "a" | 1.6246 "a" | 1.8567 |
| B | 2.3659 "a" | 1.5308 "a" | 0.8098 "a" |
| C | 3.2595 | 2.2278 | 0.7369 "a" |

| | Alfalfa Tap and Fibrous Roots(1) (gm/4-8 inch layer) | |
|---|---|---|
| Treatment | Tap Roots | Fibrous Roots |
| B | 0.7306 "a" | 0.8002 |
| C | 0.7772 "a" | 1.4506 |

(1) Within each depth, means noted with a postscript "a" are not significantly different.

layer. However, the tap roots in this dense layer were very crooked. In Figure XII photographs of the tap roots in the compacted zones are shown. It is apparent from these pictures and data that peroxide greatly increased the amount of fibrous root development for 4 inches below the surface which was in the compacted layer.

It can be seen in Figure XI for the 8-12 inch layer that root weights were slightly higher from the 8-12 inch layer in soil with a compacted layer without peroxide than from the soil which received peroxide. It was observed in

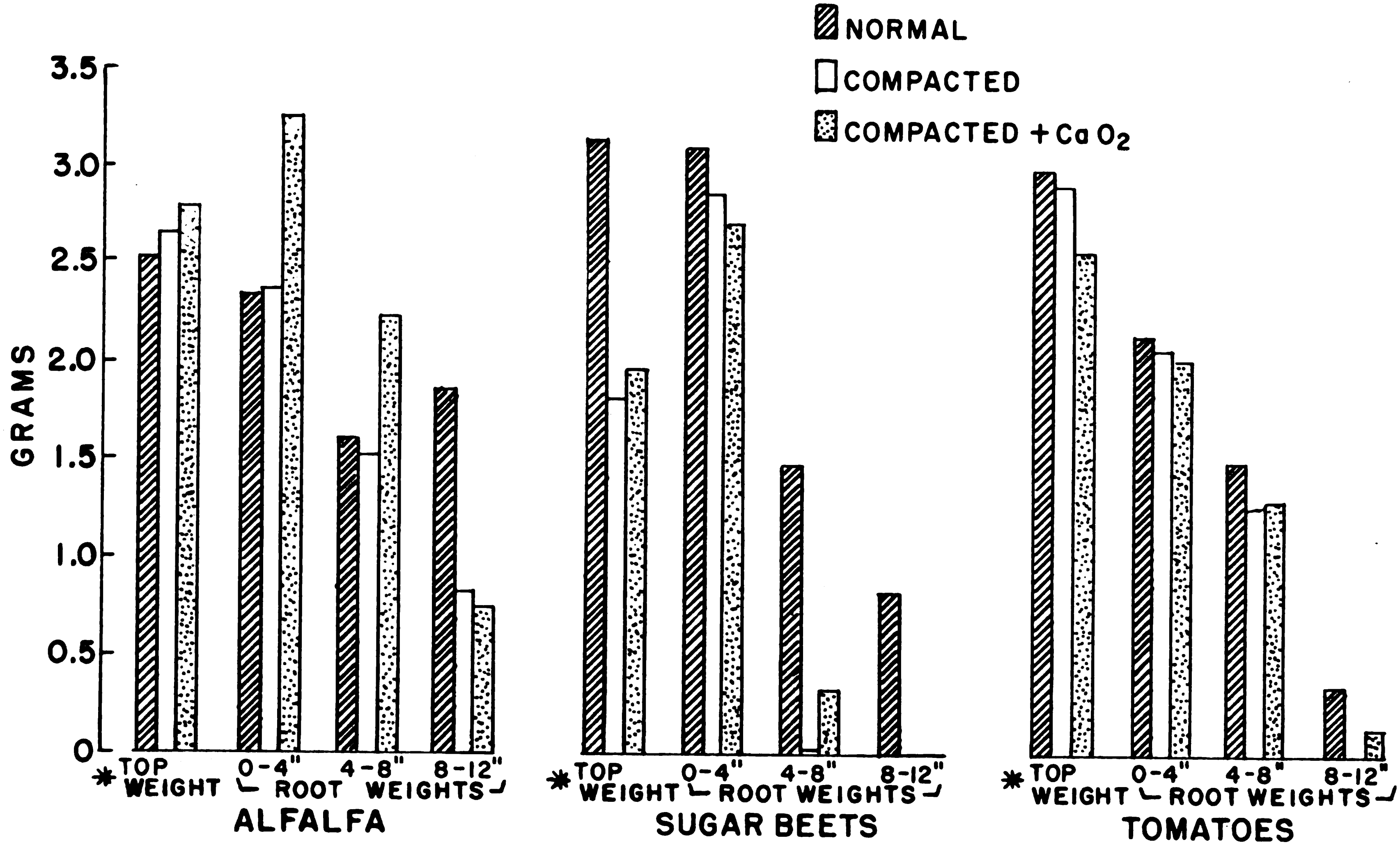



Figure XI. Weights of top and roots of alfalfa, sugar beets, and tomatoes according to four inch depth and treatment.

* Multiply given alfalfa and tomato top weights by 3 and sugar beet top weights by 4 for actual weights.

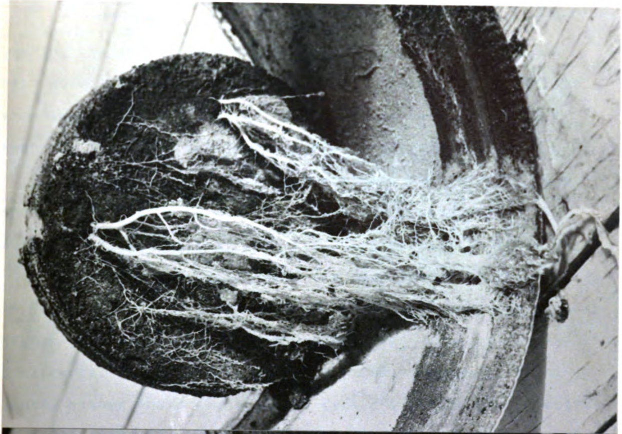
Figure XII. The effect of compaction and peroxide on fibrous root development for alfalfa.

Upper Photograph:

Alfalfa roots which did not receive peroxide and where the lower 8 inches of soil materials have been washed from the roots. Note the lack of fibrous roots growing from the tap root exposed in the 4-8 inch soil depth.

Lower Photograph:

Alfalfa roots which received peroxide in the compacted zone. Note the abundance of fibrous root development for the 4-12 inch depth.



washing the soil from the roots that where no peroxide had been added, the tap roots penetrated the compacted layer and then tended to have more fibrous roots at 8-12 inch depths than did alfalfa grown in the peroxide treated soil.

Statistical analysis of sugar beet root weights have shown significance as a result of peroxide treatments. Results of the statistical analysis are presented in Table VI.

The data for sugar beets are also presented graphically in Figure XI. It can be seen that beet tops were considerably higher in weight where no compacted layers occurred in the treatments. Root weights in the 0-4 inch layer were significantly higher where there was no subsurface zone of compaction when compared with any compaction treatment. When considering the compacted layers, there was a significant increase in root weights in the treatment receiving peroxide.

At the 4-8 inch depth, Figure XI shows that there were considerably more roots where peroxide had been used. As contrasted with alfalfa, sugar beet roots failed to completely penetrate the compacted layers. From this sugar beet data, it can be seen that there is greater root development as a result of a source of oxygen in the dense layers. Figure XIII shows a photographic comparison of sugar beet root development as affected by composition and peroxide treatment.

The weights of tomato tops and tomato roots were not significantly increased by oxygen released from peroxide. Even though the tomato plant is considered sensitive to

TABLE VI

STUDENTIZED RANGE TEST FOR WEIGHTS OF SUGAR BEET AND TOMATO ROOTS

Root Weights (gm/4 inch layer)

Sugar Beets

| Treatment(2) | Depth(1) 0-4" | 4-8" | 8-12" |
|---|---|---|---|
| A | 3.0989"a" | 1.4818 | 0.8423 |
| B | 2.8607"a" "b" | 0.0990 | 0.000 "a" |
| C | 2.7129"b" | 0.3343 | 0.000 "a" |

Tomatoes

| Treatment(2) | Depth(1) 0-4" | 4-8" | 8-12" |
|---|---|---|---|
| A | 2.1243"a" | 1.5145 | 0.3434 |
| B | 2.0693"a" | 1.2528"a" | 0.0062"a" |
| C | 2.0137"a" | 1.3040"a" | 0.0851"a" |

(1) Within each depth, means noted with a postscript "a" are not significantly different. Means noted with a postscript "b" are not significantly different at 5% level.

(2) Within treatments, any two means underscored by the same line are not significantly different at 5%.

Figure XIII. The effect of compaction and peroxide on root development of sugar beets.

Upper Photograph:

The compacted zone without peroxide has been washed from below the surface 4 inches of soil. Note that roots have failed to develop below the surface 4 inches.

Lower Photograph:

The compacted zone with peroxide has been washed from below the surface 4 inches of soil. Note the abundant root development exposed in the 4-12 inch soil depth.

oxygen conditions in the soil, an oxygen source in the dense layer did not bring about a significant root development. From data in Figure XI it is apparent that roots were found in both the treated and untreated layers. The majority of these roots were actually present in the upper portions of the compacted zones, but in only 2 containers did tomato roots succeed in completely penetrating the compacted layers which had been peroxide-treated. Evidence for this as given in the bar graph of Figure XI for the 8-12 inch soil layer.

It can be concluded from this study that mechanical impedance is not the physical soil factor which restricts the growth of roots in unconsolidated layers with a bulk density as high as 1.95 but that oxygen is the factor restricting or retarding the normal growth of roots.

## C. The Effect of Several Different Tillage Methods on the Growth and Activity of Corn Roots

### (1) Purpose

The purpose of this experiment was to determine if there was a difference in the root activity of corn as a result of four different tillage methods which altered the physical soil conditions to various depths. The root activity of corn was evaluated through the use of radioactive phosphorus techniques.

### (2) Method of procedure

The plots for this study were located on the Ewald

Fick Farm, Calhoun County, Michigan. The soil on which the plots were located is a Kalamazoo sandy loam, characterized by a B horizon which is firm when moist and hard when dry. The B horizon extends from 12 inches below the surface of the soil down to a depth of 30 inches.

Preparation of the solution containing labeled phosphorus and placement of the solution into the soil at the specified points was accomplished as described in section (2), Part B of Chapter III.

The labeled solution was placed 6 inches and 12 inches away from the plant and at 6, 12 and 18 inch depths below the plant when the corn was 4 weeks old. These treatments were placed on 4 corn plots each of which had received a different method of tillage.

Tillage treatments were established on the Fick Farm by Dr. L. S. Robertson of the Department of Soil Science and Mr. C. M. Hansen of the Department of Agricultural Engineering.

The tillage treatments were as follows:

(1) 9 inch moldboard plowing done in the spring

(2) plowing to a depth of 18 inches with a disc plow in the spring

(3) subsoiling to a depth of 28 inches with a chisel (chisel spacings were 50 inches apart) in the fall plus 9 inch moldboard plowing in the spring

(4) subsoiling to 28 inches in the fall (with 50 inch chisel spacings) plus 18 inch disc plowing in the spring.

(3) Methods of analysis

Chemical analysis of several chemical properties of the soil were determined as described in section (3) Part B of Chapter III. The results of this analysis are listed in Table VII.

TABLE VII

CHEMICAL ANALYSIS OF SEVERAL PROPERTIES OF A KALAMAZOO SANDY LOAM

| Kalamazoo Sandy Loam (Depth of samplings inches) | Cation Exchange Capacity (me/100gms) | Available Phosphorus (lbs/Acre) | pH |
|---|---|---|---|
| 4-8 | 7.22 | 75.00 | 6.2 |
| 10-14 | 7.73 | 72.00 | 5.6 |
| 16-20 | 8.55 | 165.00 | 5.1 |

Bulk densities of the soil which were determined at the 16 inch depth in the 4 different plots were as follows: 9 inch spring plowing, 1.78; 18 inch spring plowing, 1.43; 28 inch fall subsoiling plus 18 inch spring plowing, 1.52, and 9 inch spring plowing plus 28 inch fall subsoiling 1.61.

Leaf samples from the corn plants were taken for activity counts as described in section 3, Part B of Chapter III. Samples were taken after 6, 8, 10 and 12 weeks of growth.

(4) Results and discussion

Data from the absorption of labeled phosphorus by corn plants are presented graphically in Figure XIV.

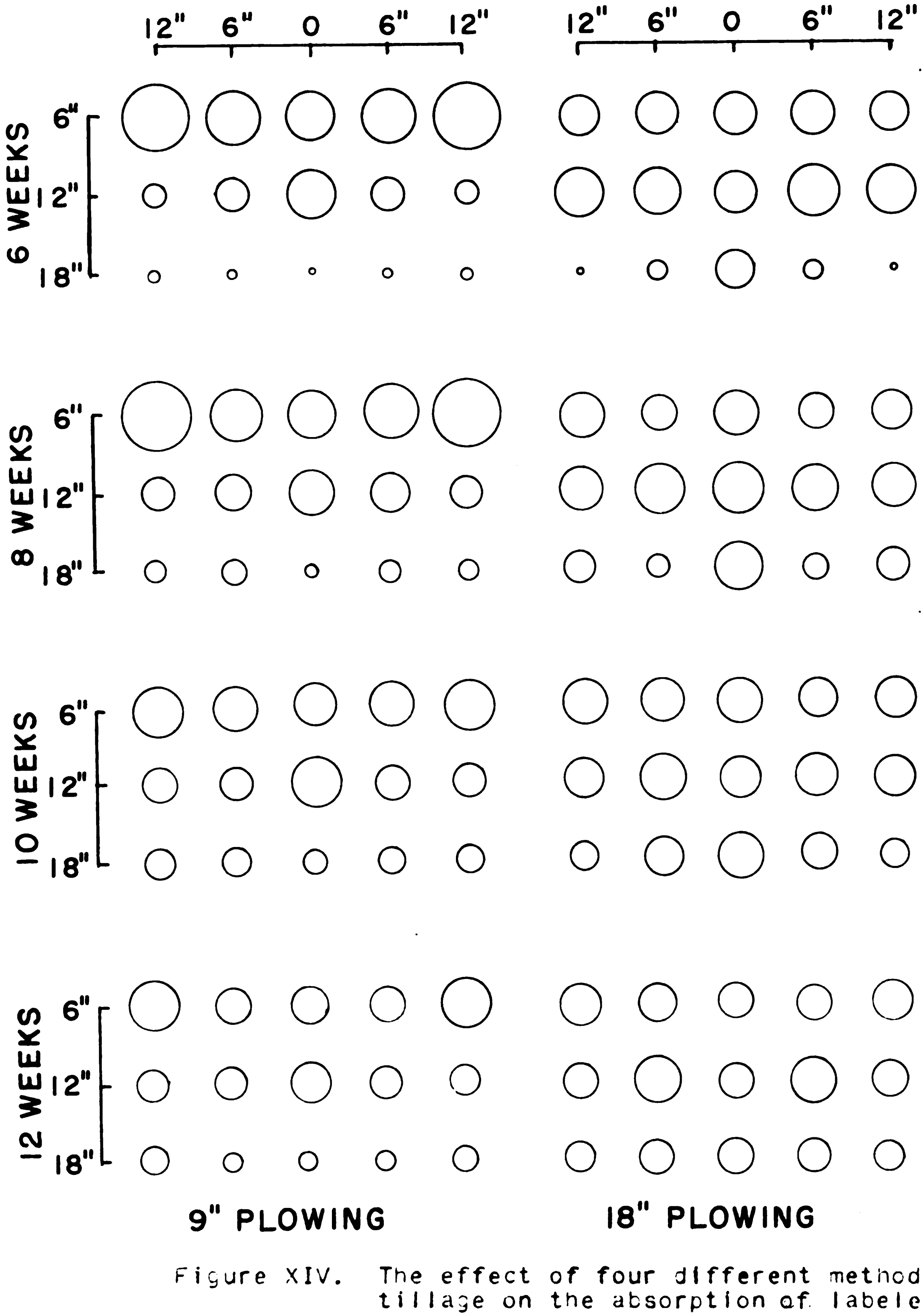
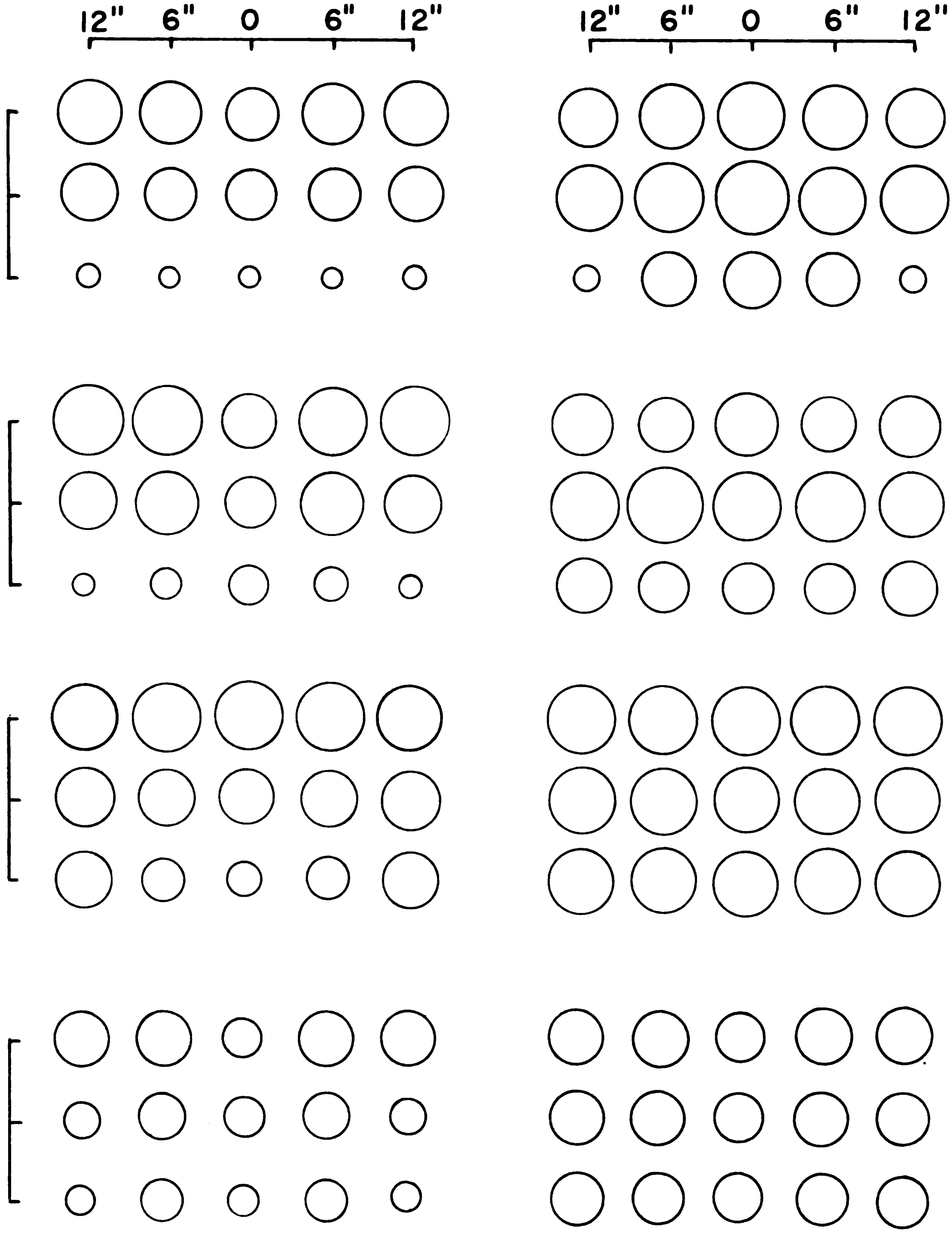



Figure XIV. The effect of four different methods of tillage on the absorption of labeled phosphorus from different positions in the soil by corn at 6, 8, 10 and 12 weeks of growth.




28" SUBSOILING
+9" PLOWING

28" SUBSOILING
+18" PLOWING

(Areas within circles represent actual values given in Table XVI). The horizontal and vertical lines represent soil surface and soil depth respectively. The "O" indicates position of plant.

Comparisons can be made between root activity measurements for different tillage treatments and for given stages of corn growth. For a given tillage treatment, root activities in both horizontal and vertical directions can be evaluated with respect to age of the corn plant.

It can be seen in Figure XIV that for all sampling dates there was an increase in development of actively absorbing roots at the 10 inch depth where tillage other than 9 inch plowing had been employed. The tillage treatment that included 28 inch fall subsoiling plus 18 inch spring plowing resulted in the greatest root activity as based on $P^{32}$ absorption by corn plants. Corn grown on soil thus treated continually absorbed more labeled phosphorus from the 18 inch depths than did corn growing on other treatments. It can also be seen that plant absorption of labeled phosphorus from soil in this treatment was rather uniform from all depths of placement irrespective of age of the plant.

Corn growing on the plot that received 9 inch plowing, exhibited root activities confined mainly to the 6 inch depth for corn 6 and 8 weeks old. Under the same tillage treatment, 10 and 12 weeks old corn absorbed $P^{32}$ in a uniform fashion from both the 6 inch and 12 inch depths.

It is interesting to note that corn grown on the plot which received 28 inch subsoiling plus 18 inch spring plowing exhibited greater root activity at 12 and 18 inch depths after 6 weeks of growth than did corn grown on plots which had 9 inch plowing after 12 weeks of growth.

Yields of corn from the four plots for 2 years are given in Table VIII.

TABLE VIII

CORN YIELDS FOR 2 YEARS FROM PLOTS RECEIVING DIFFERENT METHODS OF TILLAGE

| | bushels/Acre | |
|---|---|---|
| | 1957 | 1958 |
| 9 inch Plowing | 52.73 | 58.9 |
| 18 inch Plowing | 58.38 | 115.9 |
| 28 inch Subsoiling + 9 inch Plowing | 49.34 | 53.9 |
| 28 inch Subsoiling + 18 inch Plowing | 60.27 | 114.8 |

It is apparent that corn yields for both years were greater where 18 inch spring plowing had been one of the tillage treatments used.

Apparently the dense B horizon in the Kalamazoo soil has a retarding influence on the activity of corn roots at the 12 and 18 inch depths. Bulk densities were lowest where 18 inch spring plowing had been one of the tillage treatments. Higher bulk densities were apparent where only 9 inch plowing or 9 inch plowing plus 28 inch subsoiling had been used. These higher bulk densities occurred on the same plots reflecting the lowest corn yields.

This suggests that deep tillage has brought about favorable changes in physical soil factors such an an increase in water holding capacity and improved aeration. It would be reasonable to assume that certain chemical properties of the soil have also been improved or favorably altered as a result of deep tillage.

# V. SUMMARY

1. A preliminary greenhouse study indicated that non-radioactive Rb can be used as an indicator of root growth and activity. Absorption of Rb by corn roots in the greenhouse followed the same general trend as absorption of $P^{32}$ by corn roots.

2. Patterns of root growth and root activity were established under field conditions for corn and sugar beets. Tracer techniques indicated the volume of soil occupied by active roots with respect to age of the plant. Actual root weights compared quite favorably with amounts of labeled phosphorus absorbed from given areas in the soil.

3. Compacted layers with bulk densities as high as 1.46 in a Sims clay loam did not stop penetration of corn roots into the layer. However, compaction did temporatily retard root growth in a vertical direction.

4. A layer with a bulk density of 1.95 four inches below the surface of the soil did not stop the penetration of alfalfa tap roots. However, abundant fibrous root development on the tap root occurred only where a source of oxygen was available in the zone of compaction. Although compaction greatly retarded the vertical growth of sugar beet and tomato roots, oxygen from a peroxide source did significantly increase beet root growth in the compacted zone. Top weights of the plants did not respond

to peroxide treatments. It is concluded that aeration rather than mechanical impedance is the limiting factor in layers of high bulk density.

5. Tracer techniques indicated that 18 inch spring plowing with or without subsoiling caused considerable increase in root activity at the 12 and 18 inch soil depths. Apparently these tillage methods affected the dense B horizon of a Kalamazoo soil in such a way that the altered soil physical and chemical characteristics brought about substantial increases in corn yields. During the 1958 growing season, corn yields increased over 100% on plots which had been plowed to a depth of 18 inches in the spring.

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# APPENDIX

TABLE IX

ABSORPTION OF Rb AND $P^{32}$ BY CORN FROM MIAMI AND OSHTEMO SOILS. (mgms Igm plant material)

| Placement of tracer inches below surface | Rb uptake from Oshtemo sandy loam: sampling dates - weeks after planting 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|
| 6-8 | 1.750 | 1.500 | 2.780 | 2.915 | 2.263 | 1.950 | 1.231 | 0.937 |
| 10-12 | 0.910 | 1.033 | 2.265 | 2.349 | 1.964 | 1.915 | 1.026 | 0.881 |
| 14-16 | 0.434 | 0.416 | 0.750 | 1.091 | 1.453 | 0.942 | 0.683 | 0.560 |
| 20-22 | 0.208 | 0.350 | 0.750 | 0.849 | 1.061 | 0.627 | 0.628 | 0.504 |
| | **Rb uptake from Miami loam** — sampling dates - weeks after planting | | | | | | | |
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 6-8 | 0.810 | 3.140 | 4.820 | 4.256 | 3.619 | 2.046 | 1.638 | 1.476 |
| 10-12 | 0.400 | 0.750 | 2.300 | 3.587 | 3.191 | 2.213 | 1.764 | 1.390 |
| 14-16 | 0.344 | 0.750 | 1.325 | 1.452 | 1.549 | 1.023 | 1.064 | 0.533 |
| 20-22 | 0.035 | 0.699 | 0.700 | 0.965 | 0.940 | 0.976 | 0.583 | 0.355 |
| | **Labeled phosphorus uptake from Oshtemo sandy loam** — sampling dates - weeks after planting | | | | | | | |
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 6-8 | 0.241 | 0.344 | 0.634 | 0.664 | 0.360 | 0.394 | 0.409 | 0.435 |
| 10-12 | 0.000 | 0.242 | 0.405 | 0.293 | 0.259 | 0.371 | 0.434 | 0.418 |
| 14-16 | 0.000 | 0.000 | 0.083 | 0.158 | 0.111 | 0.125 | 0.214 | 0.179 |
| 20-22 | 0.000 | 0.000 | 0.118 | 0.144 | 0.123 | 0.133 | 0.163 | 0.156 |
| | **Labeled phosphorus uptake from Miami loam** — sampling dates - weeks after planting | | | | | | | |
| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 6-8 | 0.049 | 0.300 | 0.461 | 0.364 | 0.266 | 0.254 | 0.184 | 0.267 |
| 10-12 | 0.028 | 0.081 | 0.288 | 0.156 | 0.216 | 0.452 | 0.160 | 0.234 |
| 14-16 | 0.000 | 0.000 | 0.064 | 0.155 | 0.134 | 0.383 | 0.214 | 0.226 |
| 20-22 | 0.000 | 0.001 | 0.089 | 0.230 | 0.215 | 0.168 | 0.166 | 0.123 |

TABLE X

UPTAKE OF LABELED PHOSPHORUS BY SUGAR BEETS FROM SIMS CLAY LOAM
AS INFLUENCED BY POSITION OF PLACEMENT
(mgm phos/2 g.m. pellet)

| Treatments Distance from corn plant (inches) | | 6 weeks | | 8 weeks | | 10 weeks | | 12 weeks | |
|---|---|---|---|---|---|---|---|---|---|
| Side | Depth | Rep I | Rep II | Rep I | Rep II | Rep I | Rep II | Rep I | Rep II |
| 6 | 6 | 0.308 | 0.401 | 0.2045 | 0.216 | 0.240 | 0.271 | 0.2235 | 0.260 |
| 6 | 12 | 0.0810 | 0.0800 | 0.0858 | 0.0946 | 0.158 | 0.1501 | 0.1725 | 0.2198 |
| 6 | 18 | 0.0119 | 0.0128 | 0.0289 | 0.0284 | 0.0501 | 0.0717 | 0.0725 | 0.133 |
| 12 | 6 | 0.0350 | 0.0346 | 0.1085 | 0.1005 | 0.143 | 0.1355 | 0.139 | 0.117 |
| 12 | 12 | 0.0149 | 0.0149 | 0.0376 | 0.0343 | 0.0802 | 0.0623 | 0.0827 | 0.0779 |
| 12 | 18 | 0.00718 | 0.0099 | 0.0211 | 0.0196 | 0.0664 | 0.0383 | 0.110 | 0.0854 |
| 0 | 6 | 0.300 | 0.716 | 0.183 | 0.235 | 0.2445 | 0.220 | 0.244 | 0.233 |
| 0 | 12 | 0.088 | 0.144 | 0.0898 | 0.108 | 0.2005 | 0.146 | 0.1925 | 0.1755 |
| 0 | 18 | 0.0309 | 0.108 | 0.0585 | 0.107 | 0.1075 | 0.126 | 0.1355 | 0.188 |

TABLE XI

UPTAKE OF LABELED PHOSPHORUS BY CORN FROM MACOMB SANDY LOAM
AS INFLUENCED BY POSITION OF PLACEMENT
(mgm phos/2 g.m. pellet)

| Treatments Distance from corn plant (inches) | | 6 weeks | | 8 weeks | | 10 weeks | | 12 weeks | |
|---|---|---|---|---|---|---|---|---|---|
| Side | Depth | Rep I | Rep II | Rep I | Rep II | Rep I | Rep II | Rep I | Rep II |
| 6 | 6 | 0.745 | 0.636 | 0.952 | 0.585 | 0.648 | 0.382 | 1.410 | 0.579 |
| [illegible] | 12 | 0.176 | 0.1053 | 0.794 | 0.529 | 0.715 | 0.474 | 0.709 | 0.537 |
| 6 | 18 | 0.052 | 0.0410 | 0.126 | 0.188 | 0.413 | 0.538 | 0.494 | 0.708 |
| 6 | 30 | 0.0412 | 0.0357 | 0.0952 | 0.0558 | 0.182 | 0.158 | 0.676 | 0.419 |
| 12 | 6 | 0.970 | 0.322 | 1.39 | 0.554 | 1.130 | 0.347 | 1.212 | 0.590 |
| 12 | 12 | 0.174 | 0.090 | 0.445 | 0.499 | 0.460 | 0.512 | 0.708 | 0.558 |
| 12 | 18 | 0.0334 | 0.032 | 0.134 | 0.219 | 0.326 | 0.429 | 0.612 | 0.665 |
| 18 | 6 | 0.1699 | 0.166 | 0.922 | 1.081 | 0.637 | 0.621 | 0.870 | 0.935 |
| 18 | 12 | 0.0528 | 0.0632 | 0.195 | 0.394 | 0.342 | 0.444 | 0.440 | 0.698 |
| 18 | 18 | 0.0302 | 0.0351 | 0.0933 | 0.121 | 0.200 | 0.323 | 0.365 | 0.698 |

TABLE XII

THE WEIGHTS OF CORN ROOTS FROM 5" x 5" x 6" SAMPLING BOXES AS TAKEN AT VARIOUS DISTANCES AWAY FROM AND BELOW THE PLANT IN A MACOMB SANDY LOAM

| 6" deep | 18" | 12" | 6" | Center | |
|---|---|---|---|---|---|
| | .2975 | .2898 | .8683 | 16.3302 | 12 weeks |
| | 1.1480 | 1.0218 | 1.3689 | 4.1905 | 10 weeks |
| | .6411 | .3128 | .8460 | 1.8326 | 8 weeks |
| | .0026 | .2819 | .4227 | 1.0484 | 6 weeks |
| 12" deep | .0766 | .1515 | .7373 | 2.0118 | 12 weeks |
| | .4888 | .2887 | .9838 | 2.0373 | 10 weeks |
| | .1044 | .1741 | .5253 | .3120 | 8 weeks |
| | .0273 | .0119 | .0606 | .0722 | 6 weeks |
| 18" deep | .0467 | .0318 | .4065 | .7054 | 12 weeks |
| | .0986 | .1697 | .2728 | .4424 | 10 weeks |
| | .0136 | .0651 | .0255 | .0984 | 8 weeks |
| | .0000 | .0275 | .0141 | .0000 | 6 weeks |

TABLE XIII

YIELDS OF ALFALFA TOPS AND ROOTS AS AFFECTED BY COMPACTED LAYERS AT VARIOUS DEPTHS

| Soil Depth inches | Normal (no compaction) Rep I | Rep II | Rep III | Rep IV |
|---|---|---|---|---|
| 0-4 | 1.6073 | 2.5867 | 3.1719 | 2.0485 |
| 4-8 | 0.8253 | 1.4843 | 3.2485 | 0.9483 |
| 8-12 | 1.0862 | 1.2523 | 3.7425 | 1.3459 |
| | Compacted Layer at 4-8 inches + CaO | | | |
| 0-4 | 2.2104 | 1.8120 | 2.9618 | 2.4795 |
| 4-8 tap roots | 0.7914 | 0.5997 | 1.0390 | 0.4925 |
| 4-8 fibrous roots | 0.5523 | 0.6422 | 1.0210 | 0.9852 |
| 4-8 total | 1.3437 | 1.2419 | 2.0600 | 1.4777 |
| 8-12 | 0.6352 | 0.7019 | 1.1853 | 0.7168 |
| | Compacted Layer at 4-8 inches + $CaO_2$ | | | |
| 0-4 | 4.5484 | 2.5071 | 2.2741 | 3.7085 |
| 4-8 tap roots | 1.0947 | 0.4919 | 0.3661 | 1.1557 |
| 4-8 fibrous roots | 1.6001 | 1.3195 | 1.4162 | 1.4669 |
| 4-8 total | 2.6948 | 1.8114 | 1.7823 | 2.6226 |
| 8-12 | 0.9838 | 0.4480 | 0.5566 | 0.8794 |
| | TOP WEIGHTS | | | |
| | Normal (no compaction) | | | |
| First cutting | 6.8 | 6.1 | 9.25 | 7.49 |
| Second cutting | 5.5 | 7.32 | 10.55 | 7.50 |
| | Compaction + CaO | | | |
| First cutting | 8.15 | 7.18 | 9.50 | 5.00 |
| Second cutting | 7.82 | 8.30 | 10.60 | 7.10 |
| | Compaction + $CaO_2$ | | | |
| First cutting | 5.4 | 6.6 | 10.6 | 10.25 |
| Second cutting | 10.00 | 7.25 | 7.27 | 9.50 |

TABLE XIV

YIELDS OF SUGAR BEET AND TOMATO TOPS AND ROOTS AS AFFECTED BY COMPACTED LAYERS AT VARIOUS DEPTHS

| Soil Depth inches | Rep I | Normal (no compaction) Rep II | Rep III | Rep IV |
|---|---|---|---|---|
| | | **Sugar Beet Root Weights** | | |
| 0-4 | 2.9878 | 3.0989 | 3.5962 | 2.7127 |
| 4-8 | 2.3590 | 1.0320 | 1.0205 | 1.0661 |
| 8-12 | 1.4225 | 0.7723 | 0.5847 | 0.5199 |
| | Compacted layer at 4-8 inches + CaO | | | |
| 0-4 | 1.4773 | 2.1453 | 4.6968 | 3.1215 |
| 4-8 | 0.0371 | 0.0957 | 0.1727 | 0.0905 |
| 8-12 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | Compacted layer at 4-8 inches + $CaO_2$ | | | |
| 0-4 | 2.1715 | 2.1962 | 1.4334 | 5.0606 |
| 4-8 | 0.2094 | 0.3499 | 0.3192 | 0.5587 |
| 8-12 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| | | **Sugar Beet Top Weights** Normal (no compaction) | | |
| | 12.41 | 13.32 | 11.06 | 13.30 |
| | | Compaction + CaO | | |
| | 7.25 | 7.80 | 7.30 | 6.75 |
| | | Compaction + $CaO_2$ | | |
| | 10.22 | 8.10 | 6.37 | 6.90 |
| | | **Tomato Root Weights** Normal (no compaction) | | |
| 0-4 | 1.3001 | 2.2066 | 1.6322 | 3.3582 |
| 4-8 | 0.5948 | 0.97'7 | 0.7001 | 0.7915 |
| 8-12 | 0.0924 | 0.6342 | 0.1139 | 0.5332 |
| | Compacted Layer at 4-8 inches + CaO | | | |
| 0-4 | 1.4507 | 2.5506 | 1.7630 | 2.5132 |
| 4-8 | 1.0046 | 1.5229 | 0.9768 | 1.0171 |
| 8-12 | 0.0000 | 0.0212 | 0.0037 | 0.0000 |
| | Compacted Layer at 4-8 inches + $CaO_2$ | | | |
| 0-4 | 1.5555 | 3.0007 | 1.3810 | 2.1175 |
| 4-8 | 1.4916 | 1.7435 | 0.8810 | 1.0999 |
| 8-12 | 0.0000 | 0.0000 | 0.2290 | 0.0314 |

TABLE XIV (continued)

| Rep I | Rep II | Rep III | Rep IV |
|---|---|---|---|
| Tomato Top Weights<br>Normal (no compaction) | | | |
| 5.23 | 9.35 | 8.75 | 12.40 |
| Compacted Layer at 4-8 inches + CaO | | | |
| 10.90 | 7.00 | 6.70 | 10.60 |
| Compacted layer at 4-8 inches + $CaO_2$ | | | |
| 8.00 | 9.40 | 5.99 | 7.68 |

TABLE XV

AVERAGE ROOT WEIGHTS PER 6 INCH DEPTH FROM MIAMI AND OSHTEMO SOILS AS DETERMINED UNDER GREENHOUSE CONDITIONS

| Soil | Treatment | Depth of Root Sampling | Root Weights (gms/6 inch layer) |
|---|---|---|---|
| Miami | Rb | 0-6" | 15.8 |
| Miami | Rb | 6-12" | 3.52 |
| Miami | Rb | 12-18" | 3.40 |
| Miami | Rb | 18-24" | 3.62 |
| Oshtemo | Rb | 0-6" | 24.3 |
| Oshtemo | Rb | 6-12" | 5.8 |
| Oshtemo | Rb | 12-18" | 4.15 |
| Oshtemo | Rb | 18-24" | 3.75 |
| Miami | $P^{32}$ | 0-6" | 20.35 |
| Miami | $P^{32}$ | 6-12" | 5.15 |
| Miami | $P^{32}$ | 12-18" | 4.55 |
| Miami | $P^{32}$ | 18-24" | 2.28 |
| Oshtemo | $P^{32}$ | 0-6" | 14.08 |
| Oshtemo | $P^{32}$ | 6-12" | 2.6 |
| Oshtemo | $P^{32}$ | 12-18" | 3.32 |
| Oshtemo | $P^{32}$ | 18-24" | 2.48 |

# TABLE XVI

## UPTAKE OF LABELED PHOSPHORUS BY CORN AS INFLUENCED BY POSITION OF PLACEMENT AND VARIOUS METHODS OF TILLAGE
(mgms Phos/2 gm pellet)

| Distance from corn plant (inches) Side | Depth | 6 Weeks | 8 Weeks | 10 Weeks | 12 Weeks |
|---|---|---|---|---|---|
| | | 9 inch Moldboard Plowing | | | |
| 6 | 6 | 1.890 | 1.700 | 1.465 | 0.924 |
| 6 | 12 | .815 | .885 | 1.041 | 0.664 |
| 6 | 18 | .116 | .206 | 0.495 | 0.358 |
| 12 | 6 | 3.330 | 2.785 | 1.725 | 1.480 |
| 12 | 12 | .409 | .660 | 0.910 | 0.579 |
| 12 | 18 | .139 | .258 | 0.490 | 0.513 |
| 0 | 6 | 1.450 | 1.400 | 1.270 | 0.850 |
| 0 | 12 | 1.448 | 1.560 | 1.633 | 1.155 |
| 0 | 18 | .079 | 0.136 | 0.424 | 0.363 |
| | | 18 inch Disc Plowing | | | |
| 6 | 6 | 1.310 | 1.04 | 1.109 | 0.873 |
| 6 | 12 | 1.573 | 1.455 | 1.45 | 1.16 |
| 6 | 18 | 0.393 | 0.582 | 1.11 | 0.707 |
| 12 | 6 | 1.095 | 1.249 | 1.125 | 0.924 |
| 12 | 12 | 1.509 | 1.380 | 1.121 | 1.015 |
| 12 | 18 | 0.167 | 0.624 | 0.644 | 0.569 |
| 0 | 6 | 1.00 | 1.42 | 1.315 | 0.958 |
| 0 | 12 | 1.242 | 1.515 | 1.320 | 1.09 |
| 0 | 18 | 1.005 | 1.385 | 1.355 | 0.910 |

28 inch subsoiling plus 9 inch moldboard plowing

28 inch subsoiling plus 18 inch disc plowing

| | | | | | |
|---|---|---|---|---|---|
| | | 28 inch Subsoiling plus 9 inch Moldboard Plowing | | | |
| 6 | 6 | 2.144 | 2.51 | 2.33 | 1.680 |
| 6 | 12 | 1.785 | 2.31 | 2.155 | 1.310 |
| 6 | 18 | 0.3575 | 0.944 | 1.168 | 1.005 |
| 12 | 6 | 2.375 | 6.63 | 2.40 | 1.93 |
| 12 | 12 | 2.110 | 2.01 | 1.70 | 1.100 |
| 12 | 18 | 0.306 | 0.525 | 0.704 | 0.656 |
| 0 | 6 | 1.505 | 1.805 | 1.783 | 1.182 |
| 0 | 12 | 1.370 | 1.519 | 1.711 | 1.181 |
| 0 | 18 | .415 | 0.544 | 0.905 | 0.648 |
| | | 28 inch Subsoiling plus 18 inch Disc Plowing | | | |
| 6 | 6 | 2.220 | 1.960 | 2.31 | 1.605 |
| 6 | 12 | 2.840 | 2.790 | 2.805 | 1.645 |
| 6 | 18 | 1.698 | 1.840 | 2.12 | 1.415 |
| 12 | 6 | 1.835 | 2.105 | 2.89 | 2.025 |
| 12 | 12 | 2.763 | 2.615 | 2.11 | 1.53 |
| 12 | 18 | 0.502 | 1.955 | 2.25 | 1.88 |
| 0 | 6 | 2.740 | 2.355 | 2.225 | 1.76 |
| 0 | 12 | 3.140 | 2.71 | 2.45 | 1.895 |
| 0 | 18 | 1.759 | 1.820 | 2.24 | 1.625 |

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