A COMPARATIVE STUDY OF PHOSPHATE UPTAKE BY SEVERAL FIELD CROPS

A Thesis

Submitted to

the Faculty of Graduate Studies and Research

University of Manitoba

in Partial Fulfillment

of the Requirements for the Degree

Master of Science

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by

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December, 1966

ACKNOWLEDGEMENTS

The writer wishes to express his appreciation to Dr. R. J. Soper, Associate Professor, Department of Soil Science, under whose immediate supervision this investigation was carried out, for his advice and constructive criticism during the preparation of the manuscript.

He would like to express his gratitude to Drs. R. A. Hedlin, Professor and Head of the Department of Soil Science, E. R. Waygood, Professor and Head of the Department of Botany and D. W. McBride, Assistant Professor, Department of Chemistry, for their serving on the committee.

Thanks are also due to Drs. G. J. Racz, Assistant Professor, Department of Soil Science, B. R. Irvine, Assistant Professor, Department of Botany, and L. J. LaCroix, Assistant Professor, Department of Plant Science for their helpful suggestions concerning some experimental methods.

Finally, acknowledgement is made to the Faculty of Graduate Studies and Research and the National Research Council for the financial assistance during this investigation.

ABSTRACT

Ten soil and solution culture experiments conducted in the greenhouse plus one growth chamber soil experiment were designed to study the phosphate feeding abilities of several field crops. Calcareous soils were used in all but one experiment, as Manitoba has large acreages of these high-lime soils.

Radio-phosphorus P^{32} was employed. The "A" value technique was used in these studies which is based on the principle of isotopic dilution. The plants were harvested on several dates in order to study the phosphorus requirements at different stages of growth. The efficiency of the plants to absorb phosphorus from various materials was studied. The effect of the method of fertilizer application was also investigated. Split root technique was used to study the efficiency of a single root to absorb and translocate phosphorus.

The findings suggest some factors that are important to studying the phosphorus utilization by crops. The crops differed widely in their capacity to extract added phosphorus. A highly significant correlation was found between the per cent yields and "A" values of mustard, oats, wheat, barley, rape, sunflowers, corn, soybeans, peas, flax, and buckwheat. Soybeans were very efficient in extracting soil phosphorus. Rape, mustard, and buck-

wheat were very good extractors of the added phosphorus.

The fertilizer fraction of total phosphorus absorbed by the plants decreased with the plant growth and the "A" values increased as the plants reached maturity.

Rape was not found to be any better than soybeans in extracting added phosphorus if an alternate supply of phosphorus was present. Dipotassium phosphate, monoammonium phosphate, and monocalcium phosphate monohydrate were less efficient than monopotassium phosphate in supplying phosphorus to rape plants. But these sources were as good or somewhat better than monopotassium phosphate in their availability to the soybean plants. These differences could be due to the pH of the band and the diffusion of the fertilizer.

Rape obtained more phosphorus from a narrow band while soybeans absorbed more from a wide band. Phosphorus from the fertilizer crystals placed in the centre of the pot was most available to rape but it was a poor method of placement for oats, flax, and soybeans. Rape and buckwheat were found to be similar in their abilities to absorb phosphorus irrespective of the type of phosphate carrier used for making the crystals. However, the results elucidate that the mechanisms of their phosphate uptake were different. These two crops prefer to absorb phosphorus from a concentrated zone. In the field, flax usually does not respond well to phosphorus in a phosphate deficient soil, but rape responds well. This can be explained, in part at least, due to the fact that rape is more adept in extracting phosphorus from the fertilizer crystals.

The split root technique showed that a single root of rape was very efficient in absorbing large amounts of the fertilizer which seems to be due to its ability to solubilize and translocate phosphorus to the other parts. Flax and oats did not show this efficiency. The efficiency of buckwheat varied depending upon the growth of the root.

The problem of solubilizing was eliminated by using nutrient solutions. The presence of other nutrients had a favourable effect on the growth of the single roots of the plants. Although initially the single roots of all the crops were of about equal volume, the root of rape had branched out so profusely that it was a mass of roots at the termination of the experiment. A single root of flax did not absorb phosphorus from concentrated solutions. The presence of other nutrients was found to be essential for phosphate absorption by other crops particularly by rape.

There was a positive relationship between the extent of root growth and phosphorus uptake. Evidence has been presented that a single root of rape is not more efficient than buckwheat or oats in extracting added phosphorus when the size of the root is taken into consideration. The age of the plant had an important bearing on the uptake and translocation of phosphorus by a plant.

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CHAPTER I

INTRODUCTION

Phosphorus is among the major plant nutrient elements. It is incorporated into vital constituents of the cell such as nucleic acids, phospholipids, phytin and a variety of phosphorylated metabolites which mediate energy transfer processes.

Due to the continuous removal of phosphorus by plants and phosphate fixation it appears that the addition of phosphate fertilizers to the soil is usually essential for successful farming practice. In order to devise proper fertilizing plans it is essential to know the feeding capacity of plants and the availability of phosphorus from different carriers under different soil conditions. The complexity of such problems is evident from the large number of experiments done in this field all over the world. Such investigations have been facilitated to a great deal with the introduction of P^{32} tracer techniques.

In Manitoba the work on the phosphate feeding ability of plants was prompted by an observation made a few years ago in a field experiment with four crops, namely rape, oats, flax,and corn (114). It was found that only rape responded to a small amount of phosphate application. In the field, flax usually does not respond well to added phosphorus in a phosphorus deficient soil but rape responds well. Webber (114), in both field and greenhouse experiments, confirmed that there exists a considerable difference in the ability of these plants to absorb added phosphorus.

The investigations presented herein were initiated mainly to further our knowledge about:

(1) The comparative efficiency of several crops to absorb phosphorus from soil and from fertilizer under different agronomic conditions.

(2) The effectiveness of different phosphate carriers as fertilizers.

(3) The phosphorus requirements of the plants at different stages of development.

(4) The absorption and translocation of phosphorus by a single root.

And on the basis of this information an attempt was made to explain why crops differ in their phosphate absorbing characteristics.

CHAPTER II

LITERATURE REVIEW

A. THE ABILITY OF DIFFERENT CROPS TO ABSORB PHOSPHORUS

As early as 1891, Merrill (76) pointed out that the plant species differ in their ability to utilize phosphorus present in rock phosphate. Since then considerable data have been published on this subject. In a review of literature, Thomas (110) found that various plant species, when grown in media of similar concentration do exhibit selective powers with respect to any specific ion or ions. He discussed different theories that have been advanced to account for this phenomenon.

Skupinska (100) used four varieties of flax and observed that they did not differ significantly in their capacity to use fertilizer phosphate. However, other studies have shown that varieties of some crops may differ in this respect. Smith (102) found that a differential response existed even in various inbred lines of dent corn and their crosses under conditions of phosphorus and nitrogen deficiencies. Later Lyness (72) reported that the three varieties of corn, studied in detail, absorbed phosphates from sand cultures of a similar concentration in about the ratio of 3:5:7 and a close correlation was observed between response to phosphorus and the number and character of secondary roots. However, Fried (42) and Fried and Mackenzie (45) demonstrated that plants differed in their efficiency to extract phosphorus from basic calcium phosphate even if the effect of extensiveness of the root absorbing surface was eliminated. That the plant is an important factor when considering the availability of phosphate in different soils has also been emphasized by Ballard and Dean (7).

Krantz _et al_. (64) grew corn, potatoes, and soybeans on a low- and a high-phosphorus Bladen (U.S.A.) soil, and cotton and corn on a Norfolk soil. On Bladen soil, potatoes were found to be most efficient in utilizing fertilizer phosphorus and soybeans the least efficient. But the amount of total phosphorus absorbed was highest in corn and least in potatoes. The comparison with the Norfolk soil showed that corn absorbed more fertilizer as well as total phosphorus than cotton.

Fried (42) found that phosphorus from rock phosphate was most available to buckwheat, less available to the legumes, crotalaria, alfalfa, and ladino clover, and least available to the grasses, oats, millets, perennial rye grass, brome grass, and orchard grass. Similar results have been reported by Karpinskii, Zamyatina and Glazunova (59) with oats and buckwheat, Jenkins (58) with clover and perennial rye grass and Lee, Tsao, and Yun (68) with millet, soybeans and buckwheat.

Drake and Steckel (38) reported that oats growing with red clover in soil supplied with rock phosphate contained 60% more phosphorus than if grown alone. They indicated that high cation exchange roots of red clover bond calcium with a greater energy than low cation exchange roots of oats and thus solubilize phosphorus in large amounts.

Russell, Russell and Marais (97) measured the labile soil phosphate by the Larsen procedure (66). Barley, rye, and cabbage served as the test plants. It was found that for some soils the "L"* value (83) was higher for rye and cabbage than for barley. It was indicated that phosphate uptake must depend on the root surfaces reducing the free energy of entering ions. They pointed out that barley is not as efficient as rye or cabbage in lowering the free energy of phosphate.

During the same year when the above study was conducted, Nye and Foster (83) grew a range of plant species of the families Leguminoseae, Cruciferae, Gramineae and Solanaceae in three soils which were low in available

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$$*\text{"L"} = \frac{P^{31}\ \text{plant} - P^{31}\ \text{seed}}{P^{32}\ \text{plant}} \times (P^{32}\ \text{added to soil})$$

phosphorus. They found only small and agriculturally insignificant differences in the proportion of soil phosphorus to added P^{32} absorbed by the plants.

In Manitoba, Webber (114) recently observed that oats are most efficient extractors of native soil phosphorus among the three crops -- rape, flax, and oats -- included in this study. The other two crops, rape and flax were found to be about equally efficient in this respect.

Dmitrenko and Vitrikhovskii (36) compared the ability of peas, beans and lupine to absorb phosphorus from soluble and difficultly soluble forms of fertilizer. They found that the content of inorganic phosphorus was 8.17 and 6.23 times higher at ripening in peas and bean plants, respectively, grown in the presence of soluble phosphorus than in plants grown in the presence of difficultly soluble sources. On the other hand, the content of inorganic phosphorus in the lupine plants growing in the presence of soluble or difficultly soluble fertilizer was almost similar.

Dean (31), Fried (43), and Mattingly (74) have reviewed the work done on application of isotope techniques to study the availability of soil and fertilizer phosphorus to the plants.

B. AVAILABILITY OF DIFFERENT PHOSPHATE CARRIERS

Several studies have been done (1,34,35,46,85,86, 109), with P^{32} labelled fertilizers to evaluate the availability of various sources of phosphate when applied to neutral to alkaline soils. It has been found that phosphate carriers of low water solubility are less effective as to their availability to various crops (11,12,98).

Dion, Dehm, and Spinks (34,35) reported that mono-ammonium phosphate was more readily available than mono-calcium phosphate to wheat in experiments conducted in Saskatchewan. Dicalcium phosphate was relatively ineffective in supplying phosphorus to the plants. It was suggested that the lower uptake of these calcium phosphates was probably related to their easy conversion to difficultly available tricalcium phosphate forms (34).

Superphosphate has been found to be more available than any of the other calcium phosphates tested. Olsen and Gardner (85), working with Colorado soils, measured the availability of calcium phosphates to sugarbeets, wheat and barley. On the basis of their availability the carriers were graded as follows: superphosphate > calcium meta phosphate > dicalcium phosphate > tricalcium phosphate.

The availability of carriers varies with the crop and stage of growth. Olsen <u>et al</u>. (86) conducted field experiments and observed that alfalfa and potatoes absorbed about equal amounts of phosphorus from superphosphate and calcium metaphosphate. These two carriers were equally available to sugarbeets at the later stages, although superphosphate was more available at early stages. Calcium metaphosphate was superior to superphosphate for wheat and barley. Ammonium phosphate and superphosphate were found to be equally available to all these crops except alfalfa at one location. Later, Fuller (46) reported that there were only small differences in the availability of superphosphate, ammonium phosphate and liquid phosphoric acid to alfalfa or cotton. However, tricalcium phosphate was consistently found to be least efficient in both of the above studies.

Monoammonium phosphate and double superphosphate have been reported to be about equally available to oats, vetch, ryegrass and beans (1). Diammonium phosphate is equal to (16) or better than (10) monocalcium phosphate in its availability to oats depending on the method of application.

Beaton and Read (10), working with a Saskatchewan soil, showed that the availability of carriers to oat plants was in the following order: monoammonium phosphate $>$ diammonium phosphate $>$ monocalcium phosphate $>$ dicalcium phosphate dihydrate $>$ anhydrous dicalcium phosphate.

C. METHOD OF FERTILIZER APPLICATION

Early studies with phosphate fertilizers showed that the method of application plays an important role. However, Dean *et al.* (32) were the first to use radiophosphorus for such studies. In a greenhouse experiment they found that potatoes absorbed more phosphorus from superphosphate when it was applied in direct contact with the seed-piece as compared to a band placement. Similar studies were conducted by Nelson *et al.* (80,81) and Olson *et al.* (88) with other crops.

The efficiency of a particular method of fertilizer application has been found to be dependent on the type of crop under study. Blaser and McAuliffe (17) compared two methods of application with four phosphatic carriers as to their availability to a mixture of orchard grass and ladino clover. They found that drilled fertilizer was better than broadcast application with ladino clover but the reverse was true for orchard grass.

Stanford and Nelson (107) reported that the corn plants absorbed a higher percentage of fertilizer phosphorus when it was placed at seed depth and in bands on one or both sides of the seed than placing it in a single band above or below the seed. Recently, Khuspe (61) found that the phosphorus status of the petioles of peas increased to a greater extent by placement of the fertilizer than a broadcast application.

The efficiency of a particular method has also been found to be dependent on the solubility of the fertilizer. Olsen and Gardner (85) found that for sugarbeets the more soluble phosphates were more available from band placement and the less soluble ones were more available in rotiller placement.

Welch, Hall and Nelson (115) compared band placement and broadcast applications of superphosphate to soybeans. They found that 24 days after seeding fertilizer from these methods supplied 74% and 6% respectively, of the total phosphorus present in the plants, whereas about 70 days after planting fertilizer from both these methods supplied approximately 20% of the phosphorus in the plant. Similar studies on phosphorus utilization by sugarbeets as affected by placement and stage of growth were carried out by Lawton, Erickson and Robertson (67). They applied phosphate in the following three ways: drilled in rows seven inches apart and about three inches deep before seeding, single bands one and a half inches to the side and two inches below the seed at planting time, and side-dressed two months after seeding. It was reported that during first two months the band placement was superior but later on fertilizer in the drilled treatments was more available. The side-dressed phosphate was rapidly absorbed by the plants.

These studies revealed that the effect of placement is more pronounced during the early stages and becomes less important later on with increased growth of roots.

Experiments have been conducted on the variation of efficiency of placement with moisture conditions. Woltz, Hall and Colwell (117) reported that at one location, under dry conditions, side-dressing resulted in a very low uptake. But at another location, under more favourable soil moisture conditions, side-dressing supplied less phosphorus than did banding or mixing in the row at all stages except the last one.

Robinson, Sprague and Gross (95) studied the interrelations of temperature and method of phosphate application on the efficiency of phosphate utilization. They observed that band application was more efficient than phosphate mixed with the soil. This difference was more striking at the lower temperatures than at the higher temperatures.

The influence of placement depends on the soil being used. The band placement has been compared with mixing phosphorus with different soils (75,103). Mellado, Puerta and Caballero (75) found that on two of the three soils used, beans absorbed more phosphorus from band placement but the method of fertilizer application was not important in the third soil. In similar studies Speer _et al._ (103) reported that on one soil (acid) banding increased the uptake from more water soluble source but not from dicalcium phosphate. On the other hand, banding of any of these fertilizers did not show better utilization on the other soil (calcareous).

In general, with calcareous soils the band placement has not been consistently found to be superior to mixed placement. In acid soils, on the other hand, the placement of water soluble phosphates markedly affects the availability of fertilizers to the plants.

D. UTILIZATION OF PHOSPHORUS AT VARIOUS STAGES OF GROWTH

It has been demonstrated with crops such as wheat (18,35,78,104,105,106), corn (64,80,107), potatoes (57, 64,80), soybeans (25,26), cotton (80) and tobacco (80,117) that phosphorus uptake from the soil and the fertilizer varies at different stages of growth. Hydroponic experiments have also been done to study phosphate absorption at different harvest dates (19).

Investigations have been made on absorption of phosphorus from the soil and the fertilizer at different stages as affected by level of soil phosphorus (25,57,117), rate (57,117) and source (25) of the phosphate applied and various placements (117).

Spinks and Barber (106) found that during the first four weeks the wheat plants absorbed most of their phosphorus from the fertilizer but thereafter a greater amount was obtained from the soil. This is attributed to the fact that the fertilizer being close to the seed is more accessible to the roots at the early stages but with the enlargement of the root system a greater amount of soil phosphorus becomes accessible to the plant for absorption (35,80).

Field experiments were conducted by Stanford and Nelson (107) at three locations in Iowa. It was observed that the fraction of total phosphorus, in the corn plants, derived from the fertilizer increased up to the third sampling data when the values were between 10 to 30% depending on the location. At fourth stage the values ranged between 5 to 15%.

Krantz et al. (64) compared different crops as to their phosphorus content at various stages. They found that in soybeans and corn the percentage of phosphorus derived from the fertilizer decreased sharply during the growing season. However, it did not change much in potatoes. The nature of root extension and length of growing season are important in this respect. Potatoes are short-season fast-growing plants with limited root growth. On the other hand, corn is a long-season crop with an extensive root system. This partially explains the difference in the feeding ability of these two crops.

In a review of tracer studies in Saskatchewan, Mitchell (78) reported that phosphorus content in the tissue of wheat plant is higher in the earlier stages and decreases with plant growth. Recently, Racz et al. (91) reported the results of an experiment in which rape, flax and wheat were harvested at five different stages of growth. On both the fallow and nonfallow sites they found that the percentage of phosphorus in the plant tissue of all the crops, except flax on a fallow site, decreased as the plants grew older. The content of phosphorus in flax on fallow site increased from the first to the third stage and after that it decreased.

E. OTHER FACTORS AFFECTING PHOSPHORUS UTILIZATION

A number of other factors have been found to influence the uptake of soil and fertilizer phosphorus by plants.

Russell (96) states that the roots of certain plants can increase the rate at which insoluble phosphates are solubilized. This has been attributed to the production of CO_2 (52) or substances other than CO_2 (89). A relationship has been found between the feeding power and extensiveness of the root system. Lai and Lawton (65) reported that corn obtained more fertilizer phosphorus than the interplanted crops of sesame or bean. This was explained on the basis of the extensiveness of the root system of corn. However, the extent of the root system does not necessarily reflect the total active absorbing surface (54).

Investigations have been made on the role of microorganisms in dissolving soil phosphates (47,99). Gerretsen (47) observed that the microorganisms made a certain amount of phosphorus available to the plants which, otherwise, was inaccessible. The data proved that under sterile conditions the roots may take an active part in dissolving difficultly soluble phosphates.

Most of the work shows that the percentage of fertilizer phosphorus absorbed by the plants is inversely related to the level of soil phosphorus (25,43,57,80,115). Nelson et al. (81) found that the percentage of phosphorus in the plant tissue and the total amount of phosphorus absorbed by cotton and corn were influenced more by the soil phosphorus level than by the method of fertilizer application. Woltz et al. (117) found that an increase in the amount of native soil phosphorus increased the plant growth and the total phosphorus absorbed but decreased the percentage phosphorus in the plant from the fertilizer. However, no difference was found in the amount of fertilizer phosphorus absorbed by the plant.

The principle of isotope dilution has been used in determining the amounts of available soil phosphorus (8, 44,66). Fried and Dean (44) proposed the term "A" value to express this amount in terms of the fertilizer used.

Olsen et al. (84) have indicated that there is a relationship between yield response to the phosphate and "A" values.

The influence of pH on uptake of phosphorus has been reported by Arnon, Fratzke, and Johnson (3) and Arnon and Johnson (4). Tomato, lettuce and Bermuda grass were grown in nutrient solutions ranging from pH 3 to 9 and it was noted that phosphate absorption declined sharply at pH 9 but there was no distinct trend in the range of pH 3 to 8 (3).

The relation between soil möisture and uptake of nutrients has been reviewed by Wadleigh and Richards (112). Generally, the absorption of phosphorus by plants increases with an increase of soil moisture content (24,53,113,116). Fawcett and Quirk (41), however, have reported that the rate of phosphorus uptake by young wheat plants was not affected by increasing the water stress provided that the plants were not damaged by wilting. Dombovari (37) found that phosphorus uptake by alfalfa was not significantly affected by the amount of water in the soil.

Kramer and Currier (63) reported that permeability of the root cells is decreased by low temperature, which in turn affects the absorption. The uptake of phosphorus by plants decreases at the low soil temperature (60,62,69,71,118). Sycheva and Bystrova (108) suggested that the entrance of phosphorus into the plants is reduced at low temperature of the root zone. It has been reported that a low temperature has a suppressive effect on the incorporation of phosphorus into organic compounds (62). Case, Brady and Lathwell (28) studied the effects of soil temperature and phosphorus sources of different water solubility on phosphate absorption by oats.

The studies of Dalton, Russell and Sieling (30) showed that organic matter increased the availability of soil phosphate. This was attributed to certain metabolic products of decomposition which form stable complexes with iron and aluminum and thus reduce phosphate fixation in acid soils.

The influence of silicate on the absorption of phosphate by plants from the soil has been studied by Hunter (55). He concluded that when this ion is present in large amounts, the availability of soil phosphate may increase by anion exchange.

The efficiency of phosphate fertilizers in supplying phosphorus to the plant will depend on the reaction products and their availability (70). The formation of these reaction products in calcareous soils of Manitoba has been studied by Racz (90).

The effect of the particle size on fertilizer availability has been discussed (20,26,79). Bouldin and Sample (20) found that the response of corn, on an acid soil, to anhydrous and dihydrate forms of dicalcium phosphate increased with a decrease in granule size.

The effect of the rate of fertilizer application on utilization of phosphorus by plants has been studied by Jacob et al. (57), Nelson et al. (80) and Woltz et al. (117). It was found that on increasing the rate of application phosphorus percentage in plant obtained from the fertilizer also increased. Woltz et al. (117) reported that an increase in the rate of application increased the growth of the plant and the amount of phosphorus in the plant absorbed from the fertilizer and the soil.

Experimental evidence is considerable that the addition of nitrogen promotes fertilizer phosphorus utilization by corn (27,77,94), barley (49,51), oats (87,101), crimson clover (101), wheat (33,87), sugarbeets and potatoes (50) and millets (40).

The increase in fertilizer phosphorus uptake due to ammonium ion has been explained in different ways (2,15, 22,92). Rennie and Soper (92) suggested that ammonium ion does not alter the availability of the fertilizer but indirectly affects the ability of the plant to take up fertilizer phosphorus.

It has been observed that the addition of nitrogen generally increases the relative amount of roots in the zone of N-P placement and this in turn enhances the uptake of fertilizer phosphorus (51). Cole *et al.* (29) found that nitrogen placements increased the rate of phosphorus translocation to the tops of corn plants.

The effect of nitrogen on phosphorus uptake has been critically reviewed by Grunes (48).

The illumination period has been found to be critical with respect to phosphate absorption (21,23,82). Breazeale and McGeorge (21) demonstrated that the uptake of phosphorus was more rapid in light than in the dark. Later, Brewer and Bramley (23) also showed that phosphate absorption by corn seedlings was very low in dark but on exposure to light it increased rapidly. Recently, Novikov, Kazansksya and Podvalkova (82) reported that uptake of phosphorus by wheat was maximum during the illumination period.

Interest has also been focussed on the translocation of phosphorus in the plant. Biddulph (13,14) studied the uptake and movement of radioactive phosphorus in the bean seedlings. Arnon, Stout and Sipos (5) reported that forty minutes after the addition of phosphorus to nutrient solution, the newly absorbed phosphorus was detected in the leaves and tips of tomato plants over six feet in height.

CHAPTER III

MATERIALS AND METHODS (GENERAL)

A. CROPS AND VARIETIES

In the present study the following crops and varieties were used:

"Yellow" mustard (*Brassica hirta*, Moench), "Rodney" oats (*Avena sativa*, L.), "Selkirk" and "Manitou" wheat (*Triticum aestivum*, L.), "Parkland" barley (*Hordeum vulgare*, L.), "Tanka" rape (*Brassica napus*, L.), "Arlo" rape (*Brassica compestris*, L.), "Advent" sunflowers (*Halianthus annuus* L.), "Morden 88" corn (*Zea mays*, L.), "Acme" soybeans (*Glycine max.*, (L.) Merr.), "Century" peas (*Pisum sativum*, L.), "Redwood" flax (*Linum usitatissimum*, L.), and buckwheat (*Fagopyrum esculentum*, Moench, variety not known).

All these crops (except Manitou wheat) were used in the first pot experiment. Tanka rape (Argentine type) was used in all other experiments except in pot experiments 3 and 4 where Arlo rape (Polish type) was used. For pot experiment 7 the Manitou variety of wheat was used.

B. OBTAINMENT OF RADIOACTIVE PHOSPHORUS

The carrier-free P^{32} was obtained from the following two sources:

(1) Charles E. Frosst and Co., Montreal -- in the form of NaH_2PO_4, for pot Experiments 1 and 3.

(2) Atomic Energy of Canada, Ltd., Ottawa -- in the form of H_3PO_4, for all other experiments utilizing P^{32}.

C. GREENHOUSE ENVIRONMENT

The experiments were conducted in greenhouse (except pot Experiment 3). Extra light was required to lengthen the natural day-length to 16 hours. This supplementary light was obtained from "Sylvania" fluorescent tubes. Light intensity was about 800 to 1000 ft-c. in Experiments 1, 2 and 4 where FR96T12-CW-LO-235 tubes were used and about 1500 to 1600 ft-c. for other experiments where FR96T12-CW-VHO-135 tubes were used. During winter the temperature was about 70°F in day and 60°F at night. In summer it was not possible to control the temperature and it ranged from about 80° to 90°F during the day and about 70° to 75° during the night with the highest temperature in July and August.

The lights were raised from time to time to maintain a distance of about 9 to 12 inches between the light tubes and the tops of the plants.

D. HARVESTING AND PREPARATION OF THE PLANT SAMPLES FOR ANALYSES

The plants were cut into small pieces, air-dried, and then put in the oven at 70°C for 24 hours, weighed and then finely ground for analyses.

E. CHEMICAL ANALYSES

A representative sample of the plant material was wet-ashed and the amounts of total phosphorus and radioactivity were determined.

(1) Wet-ashing

The samples were digested with HNO_3-H_2SO_4-$HClO_4$ ternary acid mixture according to the procedure outlined by Jackson (56). The suggested pre-digestion with nitric acid was omitted. One gram samples were used for digestion. Whole plant material was digested whenever the yield was less than one gram.

(2) Determination of total phosphorus

The total phosphorus content was determined colorimetrically by the vanadomolybdate procedure (9). Colour intensity was measured on a Coleman Junior Spectrophotometer (Model 6A).

(3) Procedure for counting radioactivity

The original radioactive fertilizer solutions were stored in polyethylene bottles, to be used as the standards.

An equivalent volume of the radioactive phosphorus solution added to the pots was used as a standard for counting.

For radioassay (111) the solution was counted by a DM6 liquid GM tube (manufactured by 20th Century Electronics Ltd., New Addington, Croydon, Surrey, England) attached to a Nuclear Chicago (Model 161A) scaling unit.

CHAPTER IV

SOIL EXPERIMENTS

A. MATERIALS AND METHODS

(1) Isotopic dilution technique for the estimation of phosphorus uptake

"A" value* technique (44) was used. This is based on the principle of isotopic dilution in which quantitative determination of the change in specific activity is made. This technique is superior to the chemical extraction methods as the latter do not take into consideration the fact that plants absorb different quantities of phosphate from the same soil.

The concept of "A" value is based on the assumption that a plant when confronted with two sources of phosphorus, namely the soil and the fertilizer (both being equally accessible), would take up phosphorus from each source in direct proportion to the respective quantities available. Thus "A" value designates the amount of soil phosphorus available to the plant in terms of the fertilizer used.

A P^{32}-tagged fertilizer of known specific activity is added to the soil and the plants are grown. After harvest, the specific activities of the phosphorus in the plant and the fertilizer are determined. Thus the fraction of applied phosphorus that has been absorbed by the plants can be determined.

*See p.25.

From the amount of total phosphorus content in the plant samples, the amount of phosphorus absorbed from the native supply in the soil is calculated. The "A" values are then obtained using the following equation (93):

$$\text{"A" value} = \frac{\text{plant-P derived from soil}}{\text{plant-P derived from fertilizer}} \times \text{rate of application of fertilizer-P}$$

(2) Preparation of the soil

(a) Source:- The soil experiments were conducted in calcareous soils (Lakeland type) as Manitoba has large acreages of these high-lime soils. Pot Experiment 7 was conducted in noncalcareous soil (Wellwood type). The soils were collected from zero to six inch depth from plots located on the (i) Lakeland soil association, which is a group of black-meadow soils developed on medium-textured lacustrine deposits, and from (ii) Wellwood soil association, which is a group of black and dark grey soils developed on medium-textured lacustrine deposits which normally overlie stratified sand (39).

(b) Preparation:- After breaking the clods, the soil was air-dried, sieved through a $\frac{1}{4}$ inch screen and mixed thoroughly.

A representative sample of the thoroughly mixed soil was passed through a 2 mm sieve and retained for analyses. The soils were analyzed using standard laboratory procedures. Some characteristics of the soils used in this investigation are listed in Table I.

(3) Preparation of the radioactive fertilizer

For the preparation of tagged fertilizer solution, the inactive phosphate carrier was dissolved in a small volume of water. KH_2PO_4 was used as a phosphate carrier (unless otherwise mentioned). P^{32} solution was then added and the solution was diluted to a desired volume such that 10 ml of this solution supplied 20 mgm P^{31} and 10 uc P^{32} (unless otherwise stated). This solution was used for the "narrow" 10 ml-band. In Experiments 3 and 4 for a "wide" 40 ml-band, the solution used for the "narrow" band was diluted four times before banding. The procedure for the preparation of P^{32}-tagged fertilizer crystals is given in experiments concerned.

(4) Harvesting

The plants were harvested about $\frac{1}{4}$ inch above the surface of the soil. The above-ground portions were then prepared for analyses.

B. POT CULTURE EXPERIMENTS

(1) Seeding of the crops

One-half or one-quarter gallon porcelain glazed pots

TABLE I

SOME CHARACTERISTICS OF THE SOILS

Pot Experiment	Soil Type	Texture	pH	Conductivity (mmhos/cm)	Organic matter (%)	$CaCO_3$ equivalent (%)	$NaHCO_3$ extractable P (ppm)	Nitrate-N (ppm)	Exchangeable K (ppm)	Field capacity
1, 3	Lakeland	CL	7.7	0.86	5.11	16.10	3.28	22.90	234.5	20.6
2	"	VFSL	7.7	0.74	3.38	9.80	7.20	12.58	201.5	20.1
4	"	CL	8.0	1.05	3.60	27.90	2.69	4.15	68.3	25.5
5	"	SiCL	7.6	0.69	5.90	11.55	11.71	21.45	342.0	24.5
6(Soil I), and Box experiments	"	SiCL	7.3	0.56	5.63	7.80	11.15	19.05	392.0	23.7
6(Soil II)	"	VFSL	7.5	0.40	7.38	12.05	4.02	3.48	170.0	23.0
7	Wellwood	CL	6.4	0.32	6.05	Absent	18.05	8.29	310.0	28.1

were used. One-half gallon pots were $5\frac{1}{2}$ inches in diameter and 6 inches in height and one-quarter gallon pots were 4 inches in diameter and 5 inches in height. Two kilograms of soil were placed in each one-half gallon pot and one kilogram of soil was placed in each one-quarter gallon pot. Seeds of uniform size were selected in order to eliminate the differences due to nutrients stored in the seed.

The P^{32}-tagged fertilizer band was applied about one-half inch below the seeds at the time of seeding. The seeds were planted at a depth of about one-half inch below the soil surface. The pots were arranged in a completely randomized design.

(2) Care during the growing period

A few days after emergence, the plants were thinned so that the following number of plants were allowed to grow in each pot (unless otherwise mentioned): sunflowers -1, corn -1, soybeans -2, flax - 12, others - 4. Care was taken that only healthy and well-spaced plants were left to grow.

Optimum growth conditions were maintained throughout the growing period. Additional nutrients were added to the check pots, whenever included, to bring all the nutrients, except phosphorus, to the same level as in the fertilized pots. Enough nutrients were added to all the pots to ensure optimum plant growth. The pots were rotated on the bench once every week.

Water was added periodically to bring the moisture level in the soil to approximately field capacity. Wire supports were provided for the plants about 3 to 4 weeks after the germination. The leaves which fell off from the plants before harvesting were collected.

After harvesting, the pots were emptied to study the root distribution in the soil.

ABBREVIATIONS USED:

MKP = KH_2PO_4, Monopotassium phosphate.

DKP = K_2HPO_4, Dipotassium phosphate.

MAP = $NH_4H_2PO_4$, Monoammonium phosphate.

MCPM = $Ca(H_2PO_4)_2 \cdot H_2O$, Monocalcium phosphate monohydrate.

DCPD = $CaHPO_4 \cdot 2H_2O$, Dicalcium phosphate dihydrate.

OCP = $Ca_4H(PO_4)_3 \cdot 3H_2O$, Octacalcium phosphate.

EXPERIMENT 1

In Manitoba, Webber (114) conducted field and greenhouse experiments to study the phosphorus feeding habits of rape, flax and cereals. He observed that the response to the banded fertilizer phosphorus decreased as follows:

rape > oats > flax. It was found that oats were most efficient in absorbing soil phosphorus while the other two crops were about equally efficient in this respect. It was also shown that the "A" values decreased in the order flax, oats, and rape.

It was thought desirable to study in detail the phosphorus feeding abilities of some of the common field crops grown in Manitoba. The objective of the following experiment, therefore, was to observe how these crops behaved in their abilities to absorb soil and fertilizer phosphorus and whether they differed in their "A" values. This experiment would perhaps also show the differential response to phosphorus fertilizer.

Materials and Methods

One millicurie P^{32} was obtained on October 19, 1963. The required amount of monopotassium phosphate (MKP) was dissolved and P^{32} solution was added. Total volume was made up to one litre. The specific activity of this solution was 500 uc per gram of P^{31}. Ten millilitres of the tagged fertilizer solution, supplying 20 mgm P^{31} and 10 uc P^{32}, were applied as a "narrow" band in fertilized pots. Checks were included for comparison. Each treatment was replicated four times.

Mustard, oats, wheat, barley, rape (Tanka and Arlo), sunflowers, corn, soybeans, peas, flax, and buckwheat were used as the test plants. Thus a total of 96 one-half gallon pots were required. The seeding was done on October 19, 1963. The plants were harvested 48 days after seeding. Tissue samples were wet-ashed for counting P^{32} activity and total phosphorus determination.

Phosphorus content of the seeds:- The average quantity of phosphorus in 100 seeds of mustard, oats, wheat, barley, Tanka rape, Arlo rape, sunflowers, corn, soybeans, peas, flax and buckwheat was 3.14, 11.00, 15.70, 17.50, 2.78, 0.98, 40.00, 67.00, 101.20, 67.20, 3.56 and 6.30 mgm.

Results and Discussion

The data for yield of dry matter and the percentage of phosphorus in the tops of different crops are outlined in Table II.

The crops tested varied greatly in their response to phosphate fertilizer. The calculations for per cent yield* show that the magnitude of crop response increased in the order flax $<$ soybeans $<$ sunflowers $<$ wheat and peas $<$ corn $<$ barley $<$ mustard $<$ oats $<$ Tanka rape $<$ buckwheat $<$ Arlo rape. This reveals that the largest response was obtained

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$$^{*}\text{Per cent yield} = \frac{\text{Yield from check treatment}}{\text{Yield from fertilized treatment}} \times 100$$

TABLE II

WEIGHT OF OVEN-DRIED PLANT MATERIAL AND PER CENT PHOSPHORUS IN THE TISSUE OF DIFFERENT CROPS

Crop	Yield (gm/pot)			P in Plant Material (%)		
	Fertilized	Check	Difference	Fertilized	Check	Difference
Buckwheat	6.71	3.00	3.71##	0.21	0.16	0.05##
Arlo rape	3.66	1.03	2.63##	0.27	0.14	0.13##
Tanka rape	3.60	1.66	1.94##	0.27	0.20	0.07
Mustard	4.22	2.63	1.59##	0.22	0.18	0.04##
Peas	5.12	3.78	1.34#	0.20	0.16	0.04
Corn	4.73	3.08	1.65#	0.18	0.16	0.02
Oats	2.13	1.25	0.88##	0.27	0.26	0.01
Barley	1.63	1.05	0.58##	0.31	0.26	0.05##
Sunflowers	3.60	2.82	0.78#	0.19	0.16	0.03#
Soybeans	2.91	2.31	0.60	0.28	0.24	0.04
Wheat	1.34	0.99	0.35##	0.29	0.27	0.02
Flax	1.23	1.21	0.02	0.31	0.24	0.07
LSD 0.05	0.73	0.50		0.04	0.05	
0.01	0.97	0.67		0.05	0.06	

\# Significant at 5% level.

\## Significant at 1% level.

in Arlo rape whose check plants produced only 28% of the dry matter produced by the fertilized pots.

In the fertilized pots, buckwheat produced significantly greater amounts of dry matter than peas but the reverse was true in check pots. The "t" test showed that response to the fertilizer was significant at both 5% and 1% level of significance for mustard, oats, wheat, barley, rape and buckwheat; at only the 5% level for sunflowers, corn and peas; but was not significant for soybeans and flax.

The addition of fertilizer phosphorus increased the total amount of phosphorus absorbed by the crops (Fig. 1). The difference between the fertilized and the check plants in the amount of total phosphorus was significant at 1% level for all crops except flax for which it was significant at only 5% level. Under fertilized conditions, buckwheat absorbed the largest amount of total phosphorus while flax and wheat absorbed the least. The check plants of peas utilized the greatest amount of phosphorus and Arlo rape the lowest.

The phosphorus content in the plants increased as a result of fertilizer addition, as is evident from the data presented in Table II. The increase was significant in barley, Arlo rape, sunflowers, peas and buckwheat. The percentage of phosphorus in the plant material of flax

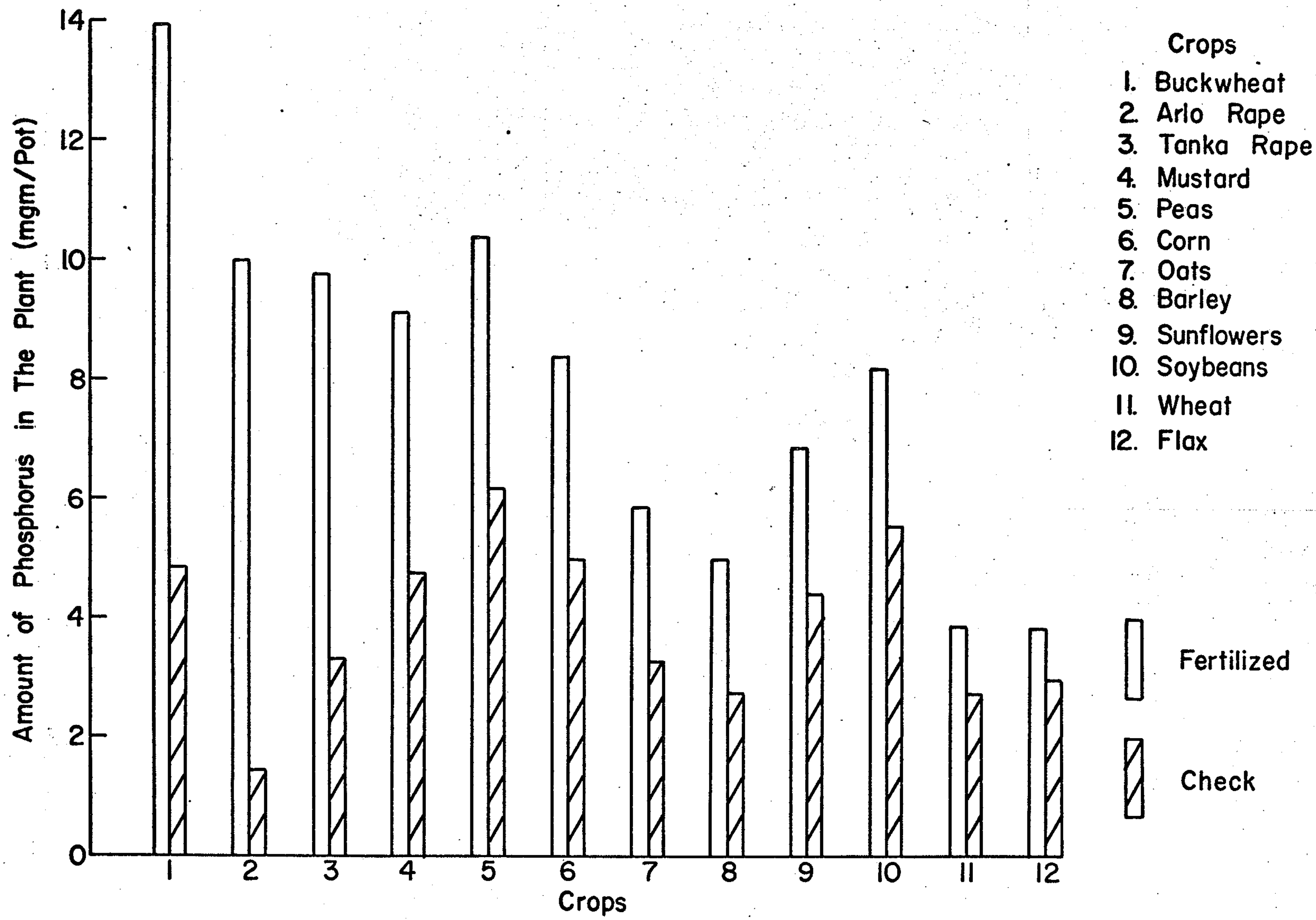

Figure 1. Uptake of Total Phosphorus by Fertilized and Unfertilized Plants

was high but because of a small amount of dry matter produced, the total amount of phosphorus utilized was very low.

The crops differ widely in their ability to absorb phosphorus from the soil and the fertilizer (Table III). The above analytical data indicate that buckwheat, mustard, and rape have a large potential to utilize fertilizer phosphorus. Peas absorbed more fertilizer than corn, oats, barley, and sunflowers which in turn absorbed more fertilizer than wheat and soybeans. The least amount of the fertilizer was absorbed by flax.

Sunflowers, corn, soybeans, and peas absorbed large amounts of soil phosphorus. On the other hand, mustard, wheat, barley, rape, and flax are poor extractors of the soil phosphorus. The amount of phosphorus in the number of seeds of the plants allowed to grow in each pot* was 0.13, 0.44, 0.63, 0.70, 0.11, 0.04, 0.40, 0.67, 2.02, 2.69, 0.43, and 0.25 mgm in mustard, oats, wheat, barley, Tanka rape, Arlo rape, sunflowers, corn, soybeans, peas, flax and buckwheat, respectively. From the soil phosphorus results in Table III, it appears that these results might have been affected somewhat in wheat, barley, peas, and soybeans due to the content of phosphorus in the seeds. Correction for the phosphorus content in seeds is difficult because it is not known what fraction of

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*See p.28.

TABLE III

THE AMOUNTS OF PHOSPHORUS ABSORBED BY DIFFERENT CROPS FROM THE SOIL AND THE FERTILIZER; AND "A" VALUE DATA

Crop	Fertilizer Uptake (%)	Fertilizer-P Uptake (mgm/pot)	Soil-P Uptake (mgm/pot)	"A" value (ppm)
Buckwheat	53.48	10.70	3.20	3.00
Arlo rape	40.87	8.17	1.82	2.16
Tanka rape	38.75	7.75	2.02	2.61
Mustard	37.94	7.59	1.52	2.03
Peas	23.87	4.77	5.63	11.79
Corn	17.62	3.52	4.84	13.79
Oats	15.92	3.18	2.66	8.61
Barley	14.98	3.00	2.00	6.72
Sunflowers	14.52	2.90	3.97	13.83
Soybeans	13.09	2.62	5.58	21.77
Wheat	10.80	2.16	1.73	8.06
Flax	7.49	1.50	2.33	15.60
LSD 0.05	4.25	0.85	0.66	2.03
0.01	5.69	1.14	0.88	2.73

this phosphorus is translocated to the above-ground portions of the plants.

The data in Table III also show that the "A" values range all the way from 2.03 ppm for mustard to 21.77 ppm for soybeans. The low "A" values for rape, mustard, and buckwheat indicate their efficiency to absorb fertilizer phosphorus more than the soil phosphorus. On the contrary, higher "A" values for sunflowers, corn, soybeans, peas, and flax indicate their capacity to extract soil phosphorus. It was found that a highly significant correlation (r = 0.77) existed between the per cent yield and the "A" value.

A few days after harvesting the plants, the soil was taken out of the pot to see the distribution of roots in the soil. The entire soil mass from each pot was sectioned vertically through the middle. This allowed inspection of plant roots in the vicinity of the fertilizer band. It was found that there was a high concentration of roots in the phosphorus band in case of rape and mustard but not in the other crops. Moreover, rape and mustard absorbed large amounts of the fertilizer. From this one might conclude that only those crops that have a high root concentration in the fertilizer band are efficient extractors of the fertilizer. However, buckwheat is a very good fertilizer feeder but did not show any marked root concentration in the band. So a lack of root concentration in the fertilizer zone does not necessarily mean that the crop is not a good feeder of the fertilizer phosphorus. The concentration of roots in the band in the case of rape and mustard, of course, may be one of the contributory factors for the higher uptake of fertilizer by these crops.

The results show that there exists a differential response to phosphorus fertilizer among these crops. They differ in the amounts of soil and fertilizer phosphorus absorbed and in the "A" values under the present experimental conditions.

The possible explanation for the reasons why these crops differ in the amounts of soil and fertilizer phosphorus absorbed might be: the extent of root growth and total absorbing surface, concentration of the roots in the fertilizer band, total phosphorus requirements of the plants, and the rate of phosphorus utilization at different growth stages.

Perhaps an experiment in which the plants are harvested at different stages of growth might shed some light as to whether the rates and the amounts of total phosphorus absorbed at different periods during the growing season are factors determining the phosphorus extracting abilities of these plants.

EXPERIMENT 2

The experiment reported earlier showed that the crops differ widely in their abilities to absorb soil and fertilizer phosphorus. It was felt that it would be appropriate to find whether these differences among the crops are consistent throughout the growing season or they are at some particular stage of development.

Soybeans, rape, flax, and oats were selected for this study. Soybeans were selected because they were found to be efficient extractors of soil phosphorus. Rape and flax were used because the former responded the most and the latter responded the least to the fertilizer phosphorus. Oats were used because of their intermediate response to the added phosphorus.

A somewhat similar study in Manitoba was previously conducted in field experiments by Webber (114). He concluded that the rates and the quantities of phosphorus taken up during the growing season were different for rape, flax, and wheat.

Materials and Methods

The radioactive phosphorus (1 mc) was obtained on July 23, 1964. Each fertilized pot received 20 mgm P^{31} and 9 uc P^{32} as a 10 ml band at the time of seeding on July 24, 1964.

Fertilized pots for the first three stages and the check pots were replicated four times. The rest of the fertilized pots to be harvested for the last four stages were replicated in triplicate. A total of 112 one-half gallon pots were required.

The first four harvest dates were 20, 35, 42, and 51 days after seeding. The fifth harvest was done 64 days after seeding for flax and 60 days after seeding for other three crops. The sixth harvest was taken 73 and 81 days after seeding for soybeans and other crops, respectively. For the final harvest, soybeans and oats were harvested 90 days from seeding and the other two crops were harvested 101 days from seeding.

Results and Discussion

The amount of dry matter produced gradually increased with the growth of the plant, although the magnitude of increase varied with different crops.

As shown in Table IV, there were large differences in plant material yields from different crops at the early stages but later on there was not much difference. At the first three harvest dates, soybeans produced the largest amount of dry matter and flax the least. Actually flax plants produced the lowest yield up to fifth harvest date. However, at the last two stages flax yield was higher than both oats and soybeans. The greatest

TABLE IV

WEIGHT OF THE OVEN-DRIED PLANT MATERIAL PER POT AND PERCENT TOTAL PHOSPHORUS IN THE TISSUE AT DIFFERENT STAGES OF GROWTH

Crop		Days after seeding						Maturity	
		20	35	42	51	#	##	Fert.	Check
Rape	Yield (gm)	0.78	2.47	3.88	6.12	9.35	12.70	13.83	12.25
	Total P (%)	0.52	0.42	0.34	0.27	0.22	0.16	0.16	0.12
Oats	Yield (gm)	0.41	2.17	3.70	6.30	8.23	9.90	9.73	10.49
	Total P (%)	0.38	0.34	0.28	0.20	0.19	0.20	0.21	0.16
Soybeans	Yield (gm)	1.21	3.60	4.54	5.93	8.33	10.23	9.67	10.28
	Total P (%)	0.19	0.18	0.26	0.31	0.31	0.29	0.33	0.25
Flax	Yield (gm)	0.29	1.24	1.68	3.88	6.58	10.22	12.37	11.13
	Total P (%)	0.19	0.52	0.55	0.30	0.23	0.14	0.13	0.09

Flax - 64 days, other crops - 60 days

Soybeans - 73 days, other crops - 81 days

amount of dry matter was produced by soybeans at the first three harvest dates and by rape at the last three stages. Oats and soybeans stopped dry matter production after the sixth stage. However, the other two crops continued dry matter production for a longer time. The typical sigmoid curve was obtained from the yield data plotted against the harvest dates. There was no appreciable difference in the yields from checks and fertilized pots at the last stage.

The percentage of phosphorus in the tissue increased in all the crops with the addition of the fertilizer. In soybeans the phosphorus content was low at the first two stages and then showed an increase, although the content did not vary much after about 50 days from seeding date (Table IV). The rape plants showed a gradual decrease in phosphorus content. Flax showed an increase up to the third stage and this was followed with a decrease in percent phosphorus. In oats the phosphorus content decreased up to fourth harvest date and did not vary much after that harvest (91).

Figure 2 shows that rape starts absorbing fertilizer phosphorus in large amounts from the very beginning. At the first harvest date, rape had absorbed about 12% fertilizer phosphorus while flax had less than 1%. At this stage rape had absorbed about six times the fertilizer

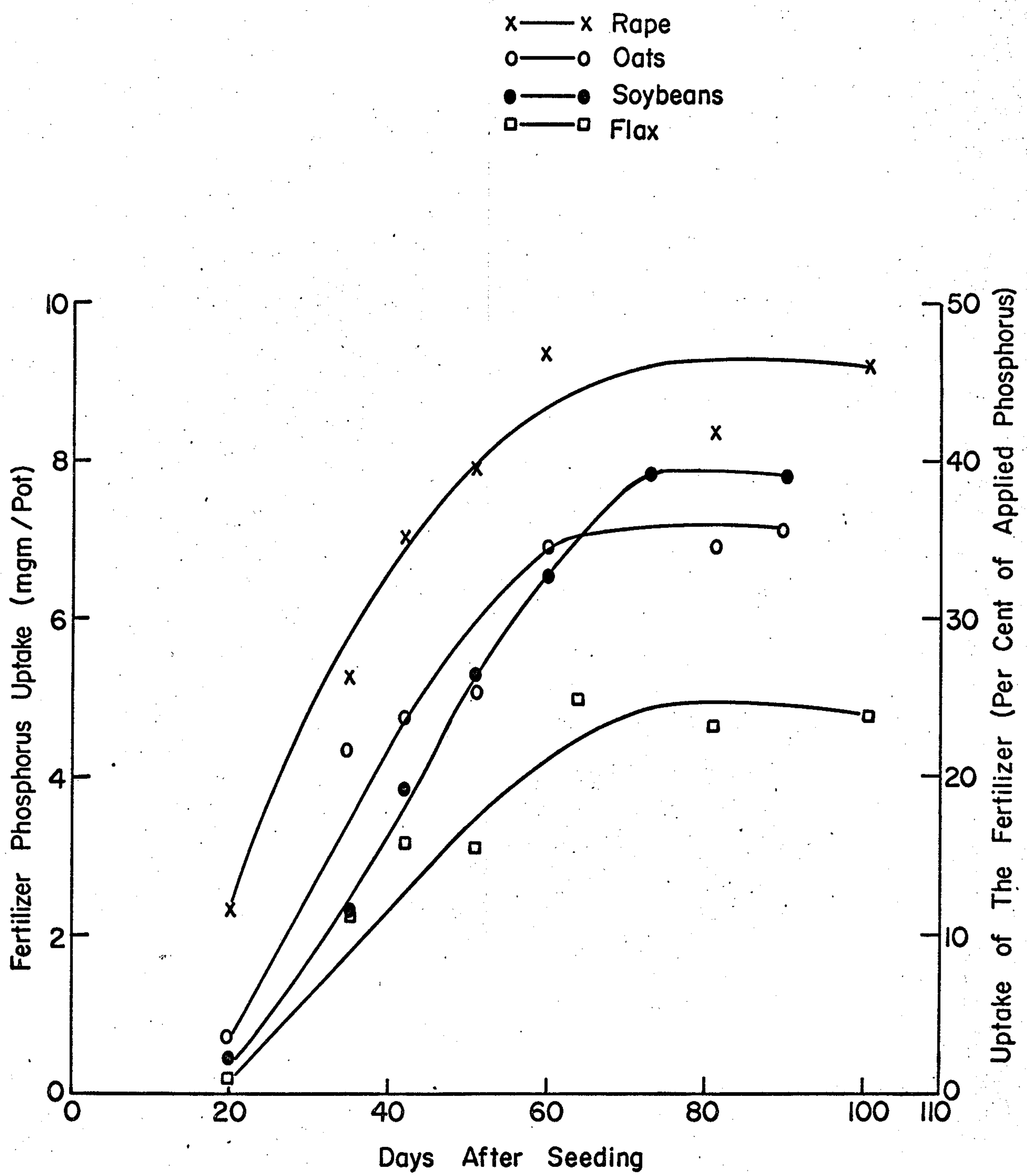

Figure 2. Uptake of Fertilizer Phosphorus at Various Harvest Dates During The Growing Season

phosphorus as that by soybeans. However, at the sixth sampling date soybeans had taken up fertilizer phosphorus almost equal to that absorbed by rape. After the fourth stage there was no increase in fertilizer absorption by rape, flax, and oats but in soybeans it was still increasing. Rape absorbed the highest amount of the fertilizer and flax absorbed the least.

Figure 3 shows the variation in the amounts of total phosphorus absorbed. At the first three harvest dates rape showed a rapid uptake but later on soybeans were found to absorb the greatest amounts of phosphorus. The total amount of phosphorus absorbed by soybeans after the fifth stage was much more than the other three crops which did not differ markedly in this respect. Total phosphorus uptake by soybeans exhibited about 40 days lag period during which the absorption was comparatively low. No such lag period was observed in other three crops.

The variation in the percentage of total phosphorus that is derived from the fertilizer is illustrated in Figure 4. Although in soybeans, flax, and oats there is an increase in the fertilizer fraction from first to second stage, all the four crops in general showed a continuous decrease with the plant growth. The initial rise seems to be due to phosphorus present in the seeds (page 35). A general decrease in the absorption of fertilizer fraction

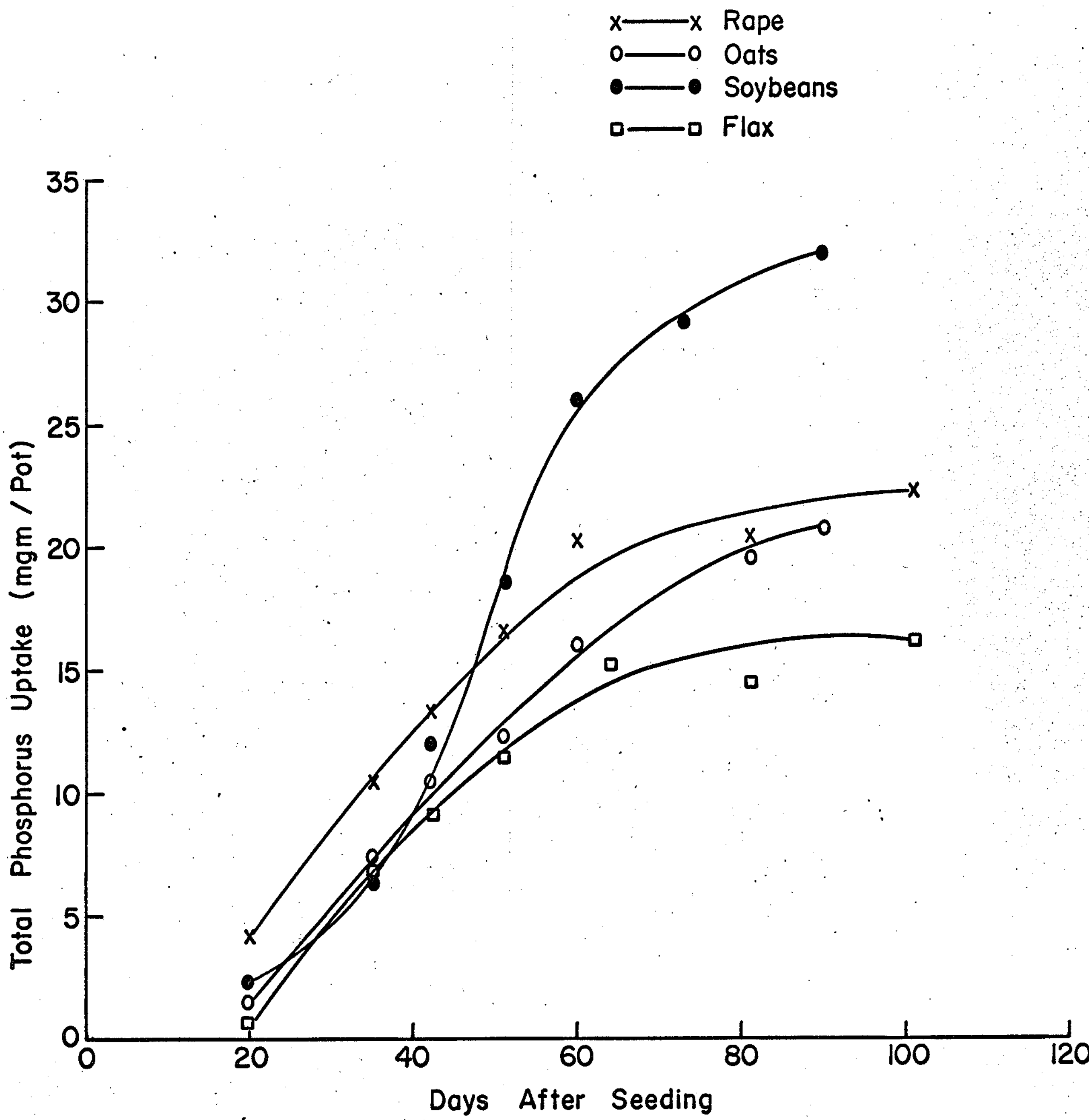

Figure 3. Amount of Total Phosphorus Absorbed by Plants at Various Harvest Dates During The Growing Season

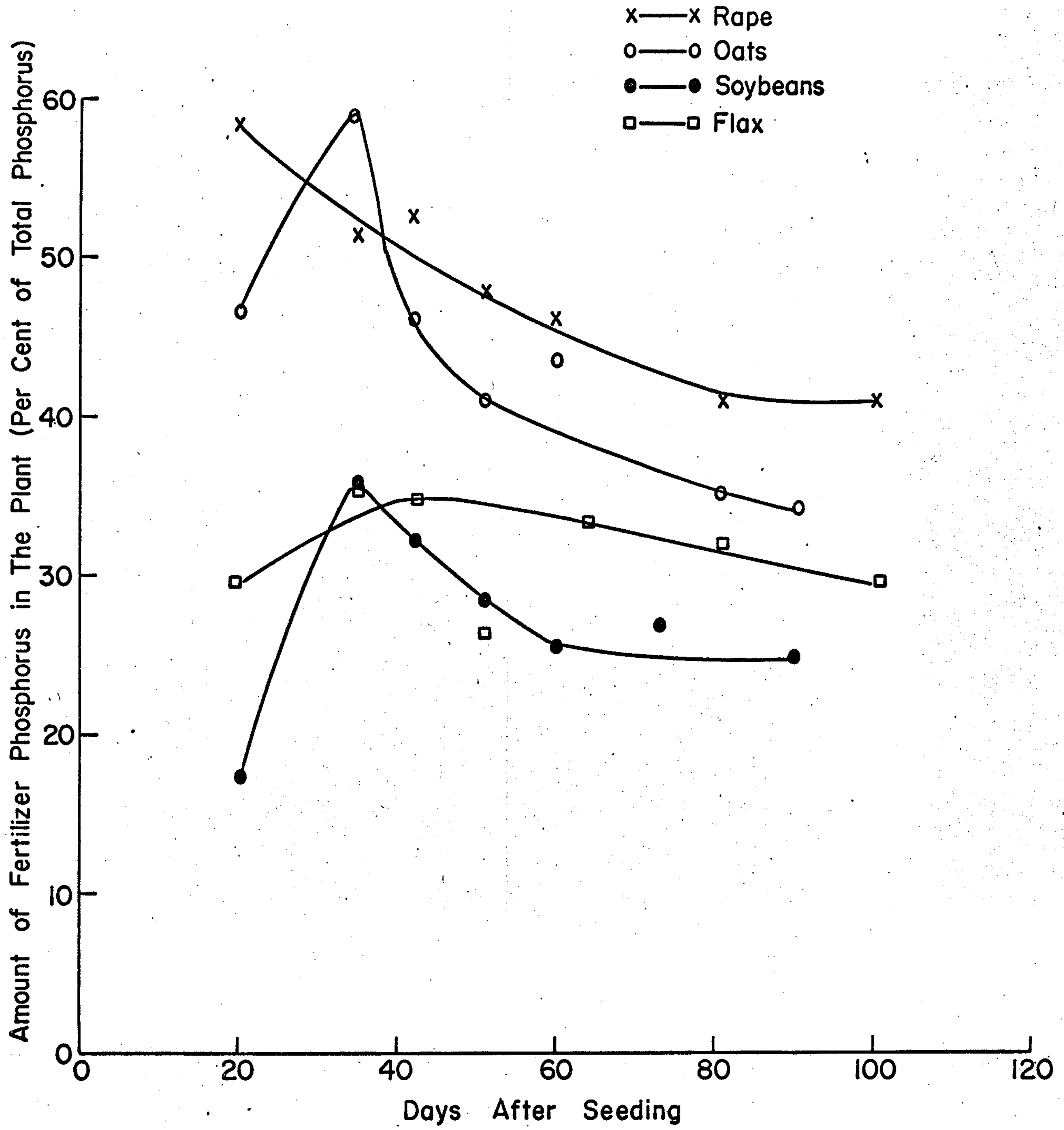

Figure 4. Effect of Age of The Crop on The Uptake of Fertilizer Phosphorus, Expressed as Per Cent of The Total Phosphorus Absorbed

may be explained on the basis that with the enlargement of the root system soil phosphorus becomes more accessible to the roots (35,80).

Rape, flax, and oats utilized substantially less soil phosphorus than soybeans (Fig.5). The amount of soil phosphorus absorbed by rape was not much different from that absorbed by flax or oats. The amount of phosphorus present in the seeds of these plants is given on page 35 . The data clearly show that the amount of phosphorus in the seeds of soybeans is much less than the difference in the amount of phosphorus absorbed by soybeans and other plants. So the seeds phosphorus does not seem to have affected the soil-phosphorus results. It shows that soybeans have a marked efficiency to absorb soil phosphorus.

In rape, both the soil phosphorus and the fertilizer phosphorus were about equally available up to the fourth harvest date but thereafter the former was being absorbed more than the latter (Fig.6). The absorption from both sources ceased after about sixty days from seeding. Figure 7 illustrates that at the first stage oats absorbed less phosphorus from the fertilizer than from the soil. The fertilizer uptake increased and after about 45 days from seeding again more phosphorus was being supplied by the soil. Moreover, fertilizer uptake virtually stopped after about 60 days from seeding but the plants continued

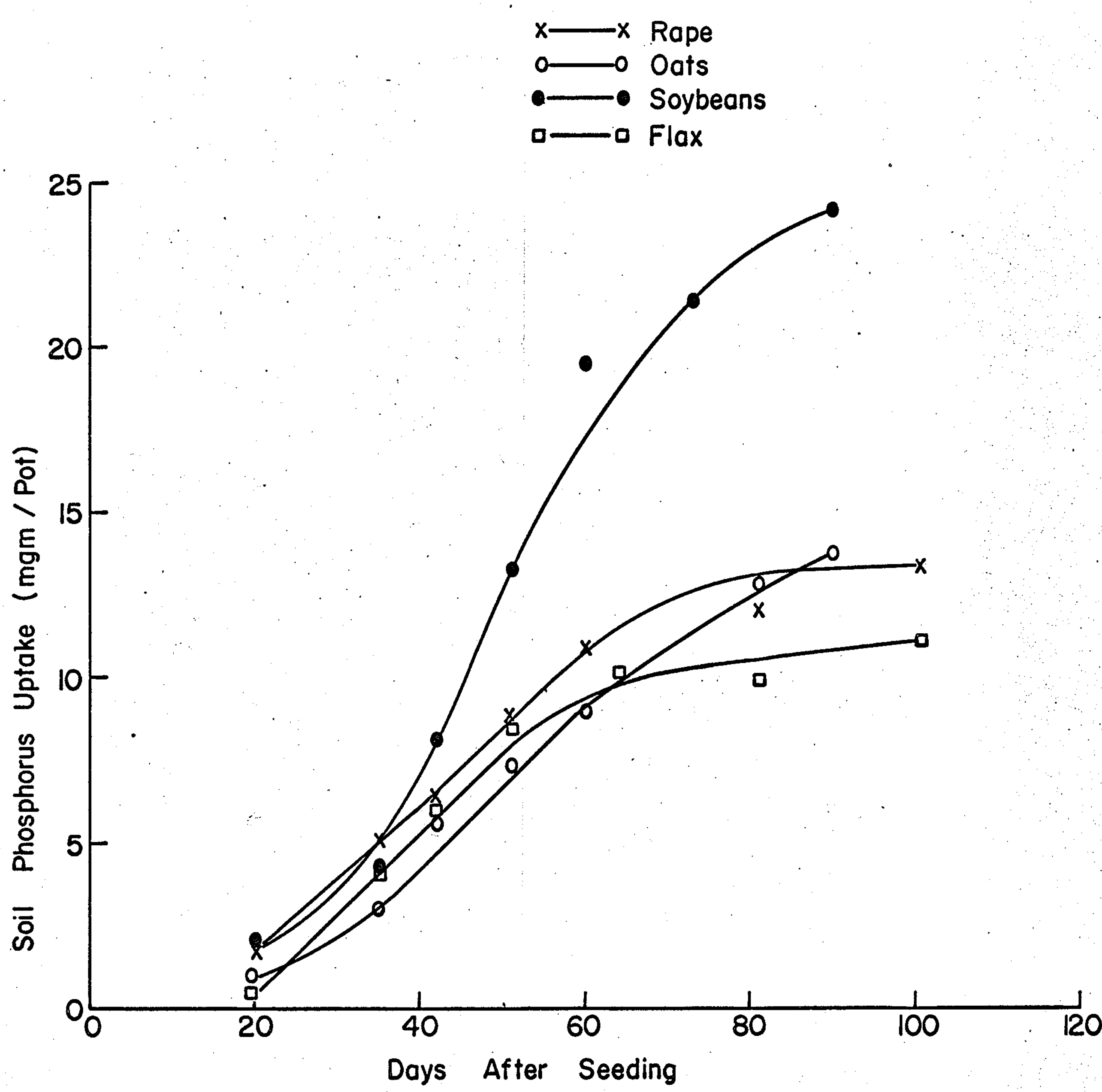

Figure 5. Uptake of Soil Phosphorus at Different Harvest Dates During The Growing Season

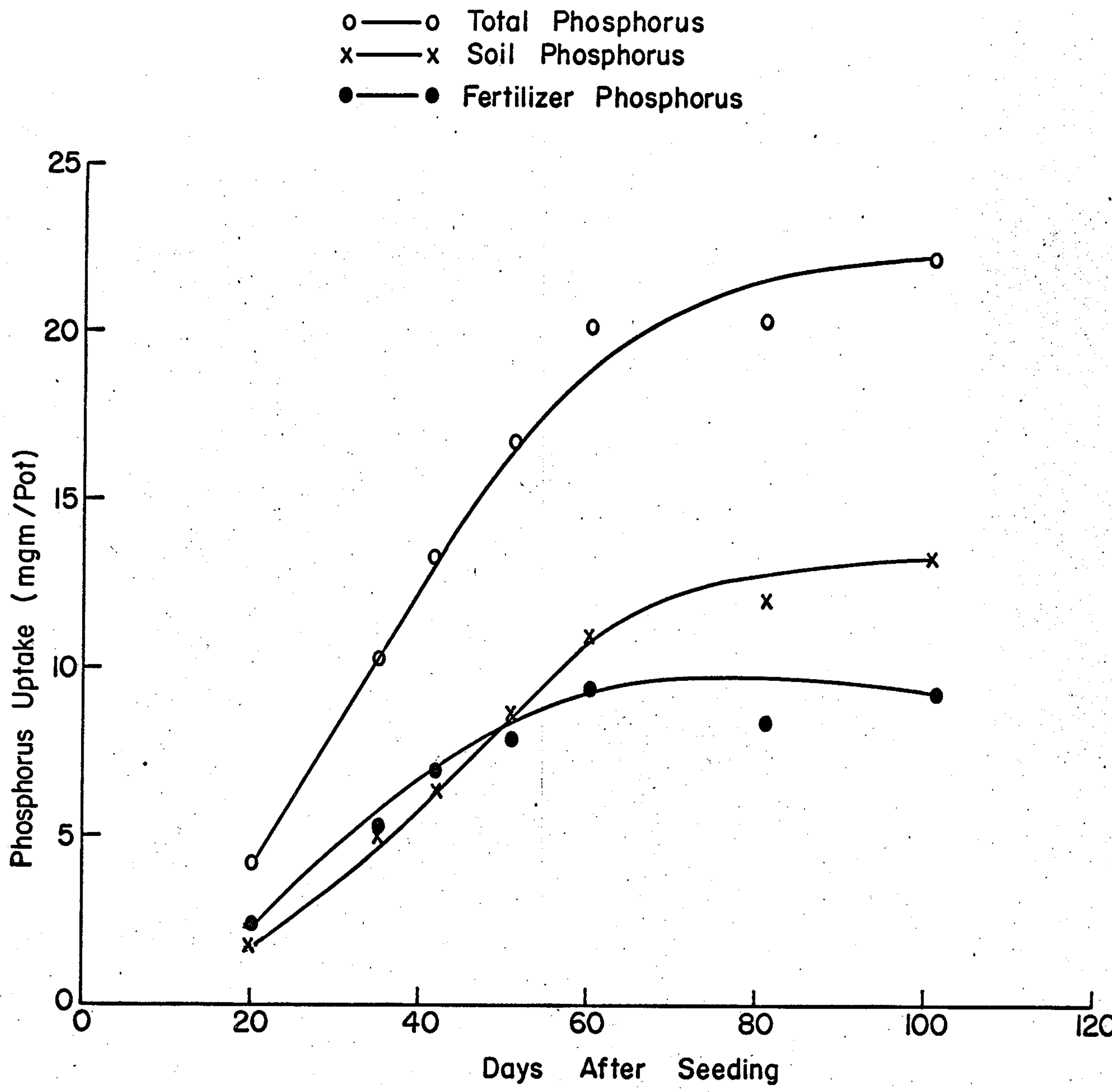

Figure 6. Uptake of Phosphorus by Rape at Various Harvest Dates During The Growing Season

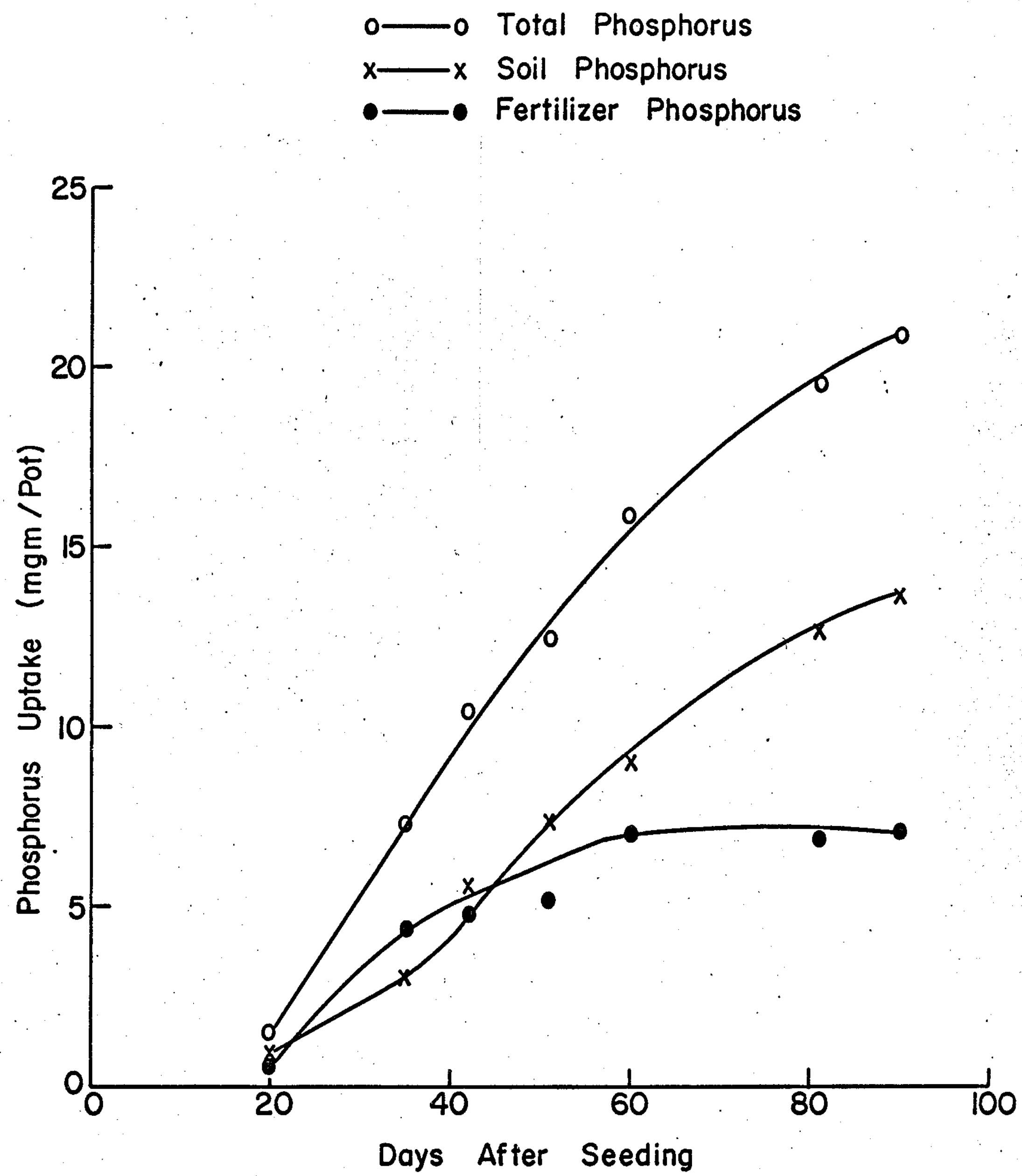

Figure 7. Uptake of Phosphorus by Oats at Various Harvest Dates During The Growing Season

absorption of soil phosphorus till a later date.

In soybeans, the soil supplied large amounts of phosphorus to the plant (Fig.8). Of the total phosphorus in the flax plant at any stage during the growing season about two-thirds was derived from the soil and the remainder coming from the fertilizer (Fig.9). The absorption essentially stopped after about sixty days from seeding.

In three of the four crops used the "A" values increased as the plant reached maturity (Table V). The root system expanded as the plant grew older and the volume of soil phosphorus in the range of roots increased (32) and thus the soil phosphorus to fertilizer phosphorus ratio increased. However, the "A" value for soybeans was much higher at the first stage than at the latter stages. The "A" value, at all stages, decreased in the order soybeans, flax, oats, and rape. This again shows the efficiency of rape in the uptake of fertilizer phosphorus.

As shown in Table I, the soil used for this experiment had higher amounts of available phosphorus than the soil employed for the last experiment. It is evident that the differences in the phosphorus feeding abilities of the plants are larger on a soil low in available phosphorus because there is no alternate good supply of phosphorus than the fertilizer.

The results of this experiment indicate that the

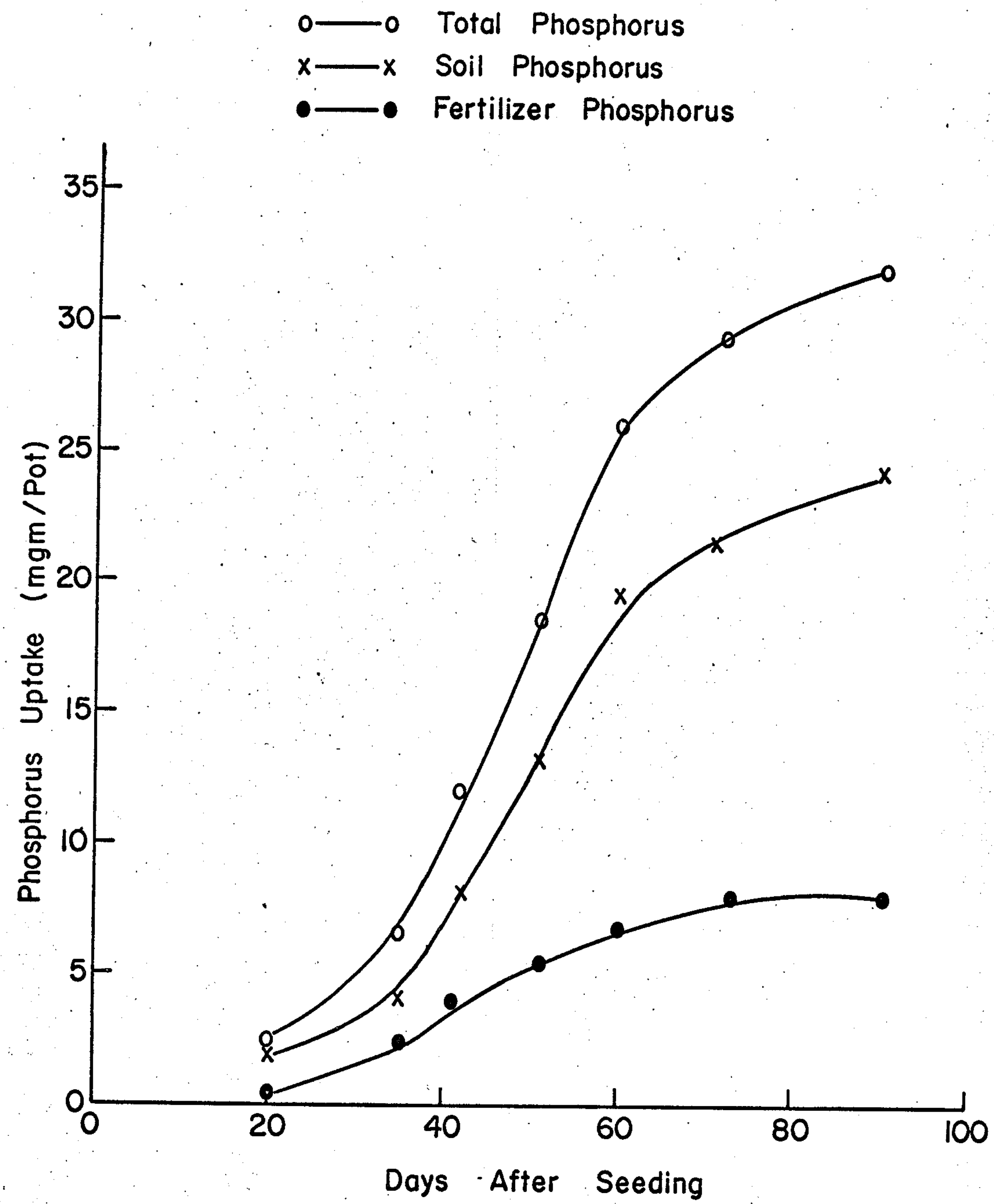

Figure 8. Uptake of Phosphorus by Soybeans at Various Harvest Dates During The Growing Season

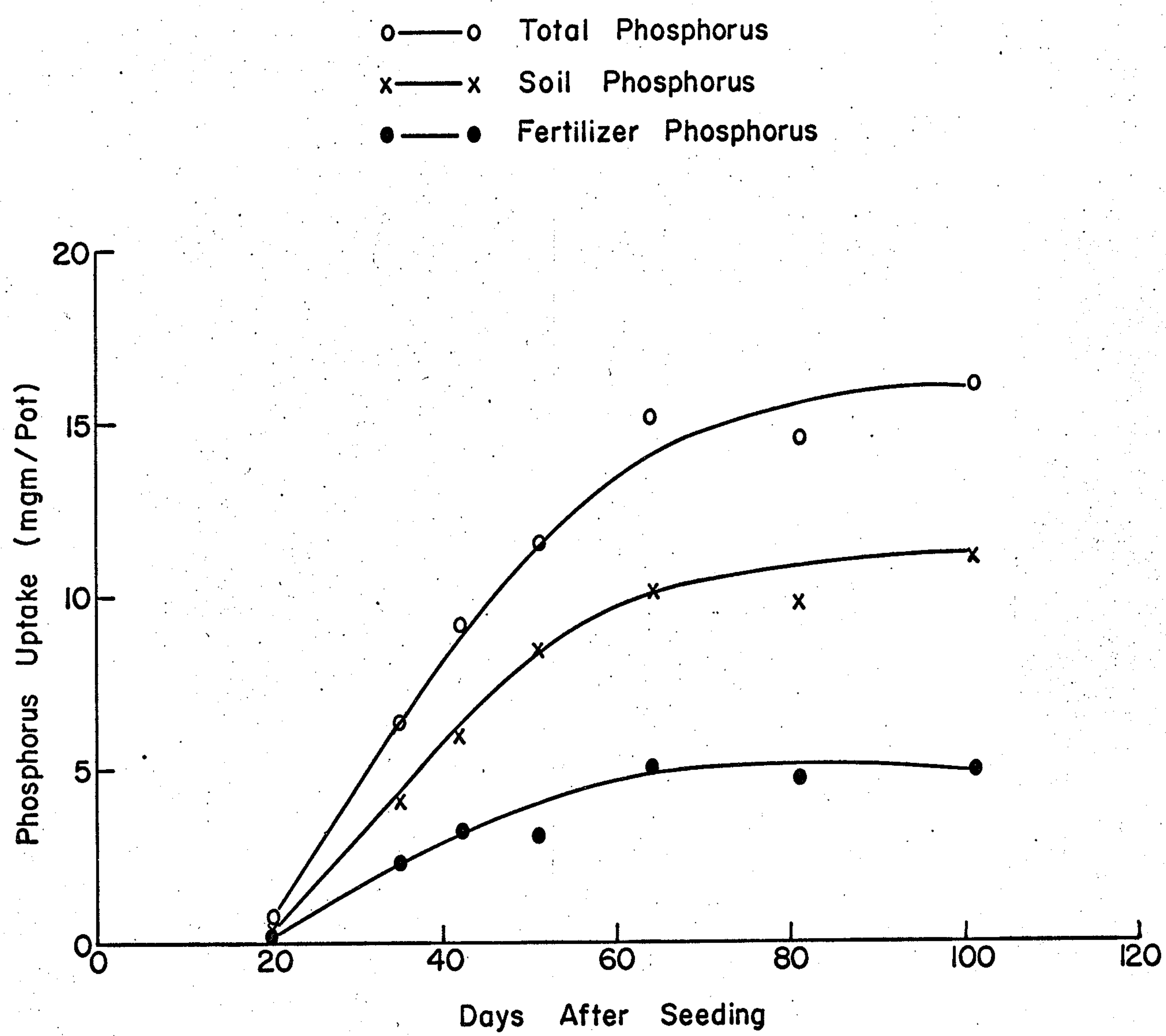

Figure 9. Uptake of Phosphorus by Flax at Various Harvest Dates During The Growing Season

TABLE V

CHANGE IN "A" VALUES WITH THE GROWTH OF THE PLANT

Crop	Days after seeding						Maturity
	20	35	42	51	#	##	
Rape	7.20	9.49	9.06	10.93	11.76	14.37	14.37
Oats	11.68	6.94	11.80	14.46	12.97	18.55	19.24
Soybeans	49.39	17.96	21.13	24.99	29.99	27.69	30.95
Flax	22.76	18.34	19.17	28.48	20.52	21.15	23.45

\# Flax - 64 days, other crops - 60 days.

\## Soybeans - 73 days, other crops - 81 days.

differences in the phosphorus feeding abilities of the crops are found throughout the growing season. The amounts of phosphorus absorbed by the plants do not change much after about sixty days from seeding. Therefore, the plants can be harvested at about sixty days from the date of sowing and it does not appear to be essential to let the plants grow up to maturity to study their phosphorus uptake abilities.

The data show that the rates and the amounts of phosphorus absorbed by the plants from the soil and the fertilizer are different for these crops. This falls in line with the findings of Webber (114) who noted that the rates and the quantities of phosphorus absorbed during the growing season were different for three crops. The variation in the utilization of soil and fertilizer phosphorus explains the differences found in the "A" values for the four crops at several harvest dates.

EXPERIMENT 3

The previous two experiments showed that crops differ widely in their phosphorus feeding abilities and these differences are present throughout the growing season. The results led to some questions: Are these differences present, (1) when the width of the fertilizer band is changed, (2) when the level of soil phosphorus is increased, and (3) when some different form of phosphate carrier is used.

Therefore, using rape and soybeans as the indicator plants, the following experiment was undertaken to study the effect of (i) mixing inactive phosphate carrier throughout the soil, (ii) the form of phosphorus fertilizer, and (iii) broadening the band, on the uptake of phosphate by these plants.

Rape and soybeans were selected because the former was found to be an efficient fertilizer phosphorus feeder and the latter was found to be an efficient soil phosphorus feeder.

<u>Materials and Methods</u>

<u>Treatments:</u> -

I. Monopotassium phosphate (MKP) band.

II. Dicalcium phosphate dihydrate (DCPD) mixed throughout the soil + MKP band.

III. Dipotassium phosphate (DKP) band.

IV. Monoammonium phosphate (MAP) band.

V. Monocalcium phosphate (MCPM) band.

VI. Monopotassium phosphate (MKP) as a "wide" band.

In treatment II, the inactive phosphate carrier, DCPD, was mixed thoroughly with the soil in the following manner:

One kilogram of soil was spread on a sheet of paper. A small amount of this soil was ground in a mortar, DCPD supplying 100 mgm phosphorus was added and mixed well with the soil. Some more soil was added, ground and mixed well again. This process was repeated a few times by adding a small amount of soil each time. The mixture of finely ground soil and phosphate carrier was then spread uniformly over the layer of soil on the sheet of paper. The soil and fertilizer were rolled on the paper a few times to ensure uniform mixing. The soil was then placed in the pot.

One millicurie P^{32} was diluted to 200 ml volume, i.e., one millilitre of this originally prepared solution contained five microcuries of the radioactivity. The calculated amounts of the carriers were dissolved, P^{32} added and diluted to desired volumes.

Phosphorus was applied as a narrow band in the first five treatments and as a wide band in the last treatment. The narrow band was prepared by applying 10 ml radioactive fertilizer solution about one-half inch below the seeds. For the preparation of a wide band 40 ml diluted solution was applied in four equal portions, each portion being covered by a small amount of soil. The seeds were planted about one half inch above the band.

Each pot received 24 mgm P^{31} and 15 uc P^{32} in the first two treatments, the quantities being 20 mgm and 12.5 uc in the other treatments. All the treatments were replicated three times. A total of 36 one-quarter gallon pots were required. The crops were sown on February 10, 1964. After the seedlings had emerged, the plant stand was thinned to one per pot in the case of soybeans and two per pot in the case of rape. The plants were harvested 54 days after seeding.

These crops were grown in a growth chamber. A 16-hour day was provided by 32 "Sylvania" fluorescent tubes (FR96T12-CW-VHO-135) and five 125 watt incandescent bulbs. Light intensity was approximately 1800 ft-c. The temperature was maintained at 70°F during the day and 60°F during the night. Relative humidity was 40-60%.

Results and Discussion

The results of this experiment are shown in Table VI and Figure 10.

The yield of dry matter produced by soybeans and rape significantly increased when DCPD was mixed with the soil in addition to the MKP band. A higher uptake* of fertilizer by soybeans from a wide band was reflected in the dry matter produced. On the other hand,rape produced less dry matter where the fertilizer was applied in a wide band. However, statistically the differences were not significant in both cases.

*Treatments I and VI received 24 and 20 mg P per pot respectively.

TABLE VI

WEIGHT OF THE OVEN DRIED PLANT MATERIAL AND PHOSPHORUS UTILIZATION BY RAPE AND SOYBEANS AS INFLUENCED BY THE PHOSPHATE CARRIER AND THE METHOD OF APPLICATION

Treatment	Yield(gm/pot)		Total P uptake (mgm/pot)		Fertilizer uptake (%)		"A" values (ppm)	
	Rape	Soybeans	Rape	Soybeans	Rape	Soybeans	Rape	Soybeans
I	6.03	5.42	12.53	12.04	43.46	29.11	4.83	17.39
II	7.78	7.15	29.58	33.62	17.14	16.07	148.82	186.83
III	6.25	6.28	9.55	11.51	34.67	27.59	7.62	21.73
IV	5.41	5.66	9.26	11.45	27.44	23.99	13.71	27.78
V	6.27	5.62	9.08	12.11	32.85	32.15	7.61	17.69
VI	4.97	5.89	9.05	13.52	26.36	32.76	14.20	21.24
LSD 0.05	1.15	0.86	2.28	1.03	4.67	2.30	8.88	16.99
0.01	1.61	1.21	3.19	1.45	6.54	3.22	12.46	23.81

Treatment:
- I Monopotassium phosphate band.
- II Dicalcium phosphate dihydrate mixed and monopotassium phosphate band.
- III Dipotassium phosphate band.
- IV Monoammonium phosphate band.
- V Monocalcium phosphate monohydrate band.
- VI Monopotassium phosphate "wide" band.

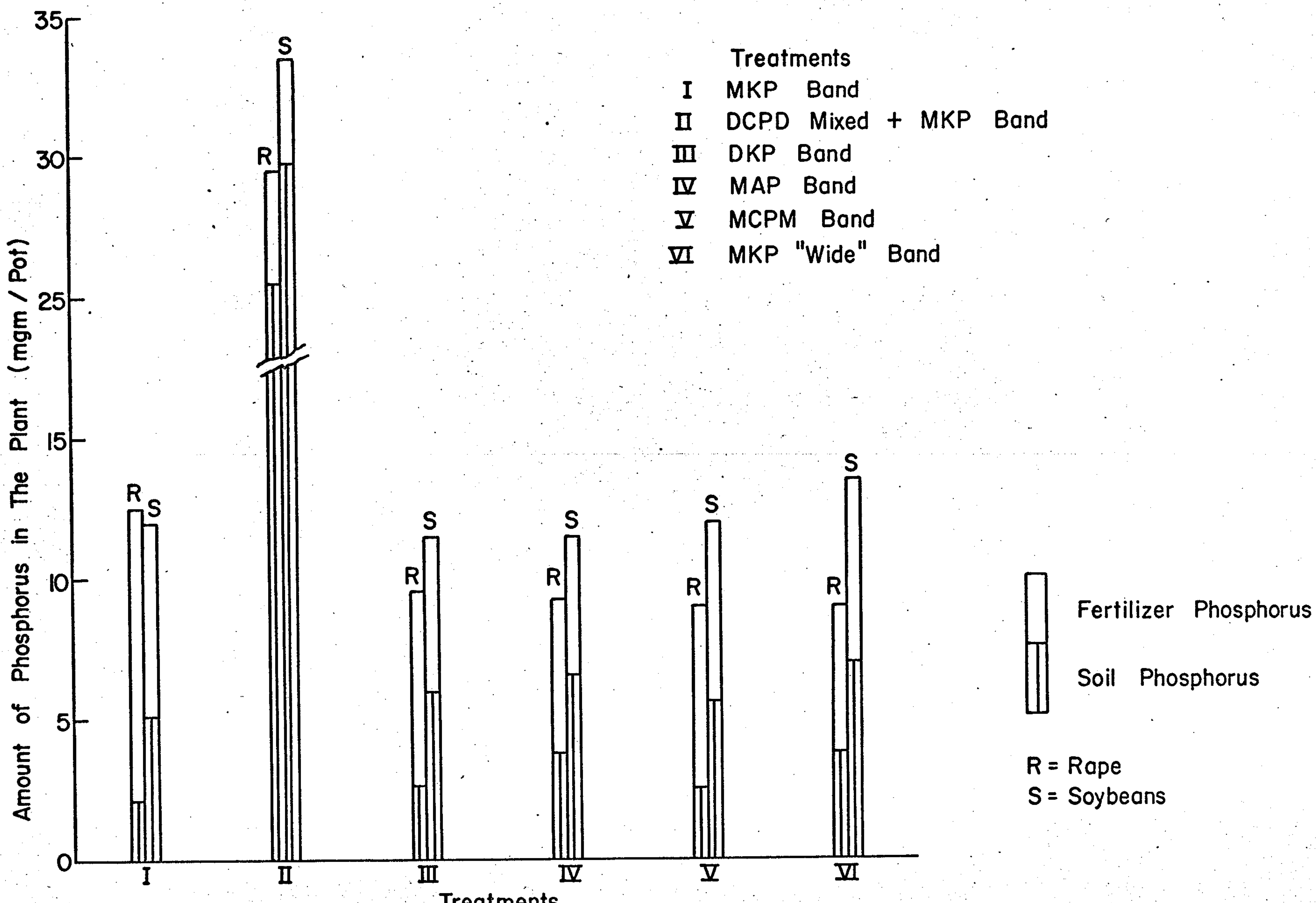

Figure 10. Contribution of Soil Phosphorus and Fertilizer Phosphorus as Affected by The Form of The Carrier and The Method of Fertilizer Application

Mixing of the inactive phosphate carrier with the soil significantly increased the phosphorus content in the plants.

The results show that the mixing of a nonradioactive phosphate carrier with the soil decreases the absorption of the fertilizer from the band. There was a larger decrease in the uptake of MKP by rape than by soybeans when the level of soil phosphorus was increased by mixing DCPD. From this treatment, both crops absorbed about equal amounts of the fertilizer from the band. It shows that if an alternate good supply of phosphorus is present, rape does not take up more phosphorus from a band than do soybeans.

The availability of the different phosphate carriers varies with the crop under study. The differential availability of fertilizers to the crops is indicated by the data of Beaton and Read (10), Fuller (46), Olsen and Gardner (85), and Olsen *et al*. (86). Rape absorbed more phosphorus from MAP than did soybeans. Both MKP and DKP were more available to rape than to soybeans from a narrow band. In short, DKP, MAP or MCPM is not as good a source of phosphorus to rape as is MKP, but is as good or somewhat better for soybeans. These differences could be due to the pH of the fertilizer band or to the diffusion of the fertilizer in the soil.

The higher uptake of phosphorus from MCPM by soybeans could be due to the fact that it might have diffused into a larger area than DKP. Thus a narrow band of MCPM might have expanded and thus behaved to some extent like a wide band. Probably due to this reason its uptake by soybeans was more and by rape was less than from a narrow band of MKP or DKP. The difference in the availability of MAP can not be explained on the basis of its diffusion outside the band.

It is interesting to note that a wide band of MKP is better than a narrow band for soybeans but is less efficient than a narrow band for rape. This indicates that rape prefers to absorb fertilizer from a narrow band and soybeans prefer from a wide band. This difference between the crops is probably due to a different pattern of the growth and distribution of the roots in the vicinity of the fertilizer band. This confirms the findings of other workers (17,32,80,115) that the method of fertilizer application plays an important role in determining the fertilizer uptake by plants. It is, therefore, important for the most efficient use of the fertilizer that the method of application should be selected very carefully.

The "A" values (Table VI) increased significantly when DCPD was mixed thoroughly with the soil. The "A" values were always high for soybeans which again shows that they are very efficient extractors of the soil phosphorus.

A distinct concentration of roots was found with rape in the vicinity of the fertilizer band in all treatments except where a non-radioactive phosphate carrier was mixed throughout the soil. This could be due to the fact that the phosphorus level of the soil has been increased sufficiently for the requirements of the rape plants and thus it is not essential to have a distinct root concentration in the band. With soybeans there was no such root concentration in the fertilizer band. This may probably be one of the reasons why soybeans are less efficient in absorbing the fertilizer.

The following experiment was more or less a repetition of the previous experiment.

EXPERIMENT 4

The last experiment showed that if an alternate good supply of phosphorus is present, rape does not absorb more phosphorus from a band than do soybeans. The two crops were found to be different in their feeding abilities when different phosphate carriers were used or when the width of the fertilizer band was changed. Rape absorbed more fertilizer from a narrow band than did soybeans but fertilizer uptake by soybeans was higher than by rape when the width of the fertilizer band was increased.

The plant growth was not normal in soybeans in the previous growth chamber experiment. The height of the plants varied, probably due to some genetic character, from one foot for MKP wide band to two and a half feet for DCPD mixed treatment although the plant weights for these two treatments were not very different. Therefore, it was felt that a similar experiment should be carried out in the greenhouse in which checks should also be included.

Materials and Methods

This experiment consisted of the following treatments:

I. Monopotassium phosphate (MKP) band.

II. Dipotassium phosphate (DKP) band.

III. Monocalcium phosphate (MCPM) band.

IV. Monopotassium phosphate (MKP) as a "wide" band.

V. Check.

The treatments were replicated three times. Thus a total of 30 one-quarter gallon pots were required. As in the last experiment, the soil used for the present experiment was very low in the amount of available phosphorus.

One millicurie P^{32} was obtained on June 1, 1964. At the time of seeding, on June 2, 1964, the labelled phosphate fertilizer (10 ml in treatments I to III and 40 ml in treatment IV) was banded in the soil. Each fertilized pot received 20 mgm P^{31} and 12.5 uc P^{32}.

A few days after germination, the plants were thinned to one per pot in soybeans and two per pot in rape. The plants of rape and soybeans were harvested 48 and 60 days respectively, after seeding.

Results and Discussion

Table VII presents the oven-dry plant weight and phosphorus utilization data for rape and soybeans.

The addition of fertilizer increased the yield of dry matter produced by both the crops. Rape showed a greater response than soybeans. The yield increase was statistically significant at 1% level for treatments II and IV of soybeans and all the treatments of rape.

The data show that rape, as compared to soybeans, absorbed much more phosphorus from MKP and DKP but the MCPM band application was about equally efficient for both the crops.

Soybeans absorbed large amounts of fertilizer phosphorus from a wide band but rape absorbed more from a narrow band. As illustrated in Figure 11, soybeans are very efficient in extracting soil phosphorus.

There was a marked concentration of roots in the fertilizer band with rape but not with soybeans.

In this experiment the growth of the soybean plants was normal. The results of the present experiment are, in general, similar to those obtained in the last experiment. This indicates that the abnormal growth of soybean plants in the last experiment did not affect the uptake of phosphorus.

Three types of studies could have been carried out on the basis of the results obtained in Experiments 3 and

TABLE VII

WEIGHT OF THE OVEN-DRIED PLANT MATERIAL AND ABSORPTION OF PHOSPHORUS BY RAPE AND SOYBEANS AS INFLUENCED BY THE FORM OF CARRIER AND METHOD OF APPLICATION

Treatment		Yield (gm/pot)		Total P in plant material (%)		Fertilizer uptake (%)		"A" values (ppm)	
		Rape	Soybeans	Rape	Soybeans	Rape	Soybeans	Rape	Soybeans
I		3.03	3.01	0.29	0.29	39.31	25.74	2.26	12.83
II		2.77	3.80	0.33	0.28	40.97	30.28	2.00	15.36
III		2.64	2.76	0.31	0.34	29.71	26.25	7.67	15.25
IV		2.97	4.21	0.23	0.29	28.10	40.12	4.63	10.81
V		0.26	1.89	0.12	0.17	-	-	-	-
LSD	0.05	0.20	1.17	0.05	0.07	4.87	10.18	2.12	NS#
	0.01	0.29	1.67	0.08	0.10	7.08	NS	3.08	NS

Treatment: I Monopotassium phosphate band.
II Dipotassium phosphate band
III Monocalcium phosphate band.
IV Monopotassium phosphate "wide" band.
V Check.

NS = Not significant.

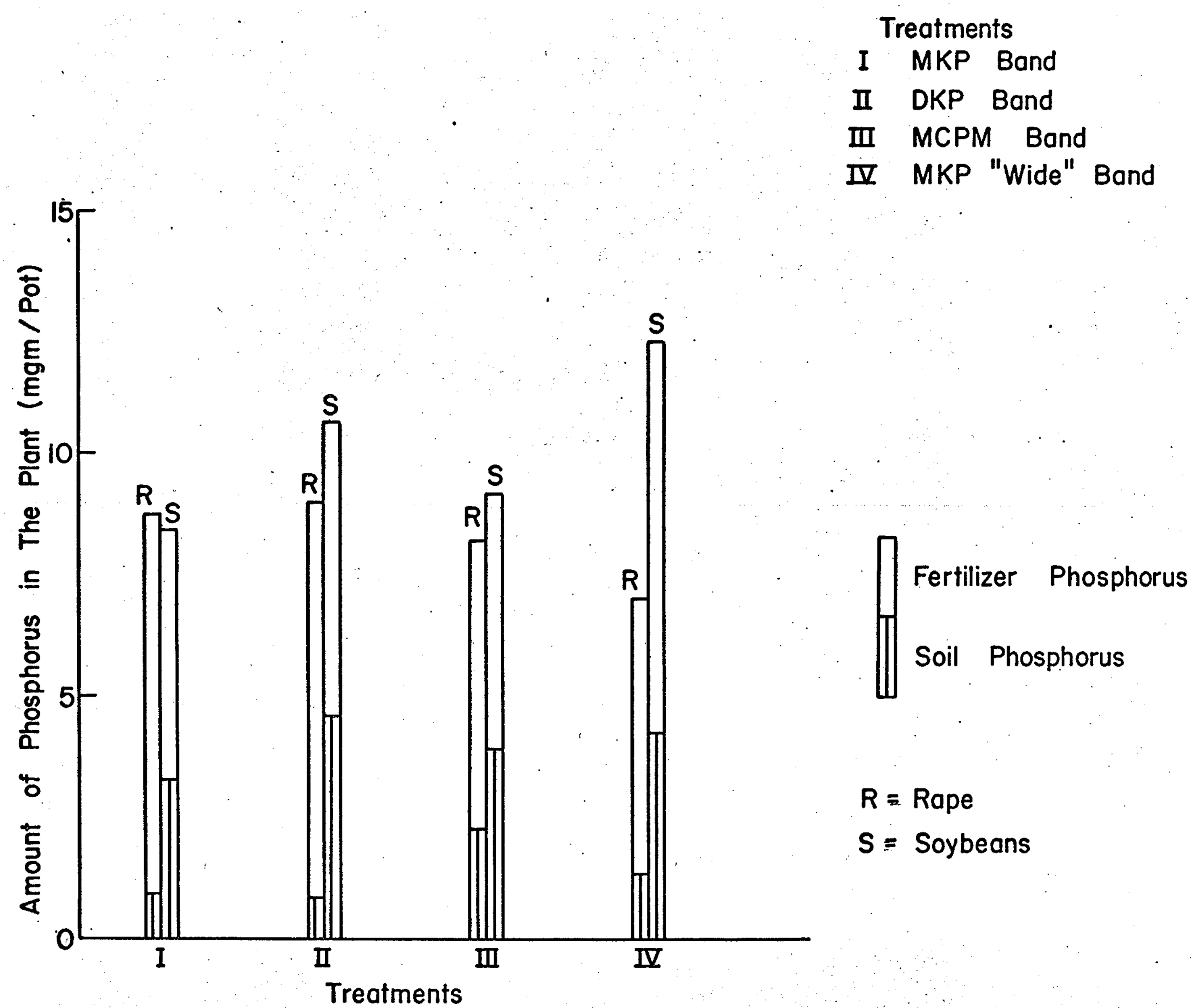

Figure II. Contribution of Soil Phosphorus and Fertilizer Phosphorus as Affected by The Form of The Carrier and The Method of Fertilizer Application

4, viz., the narrow and the wide band treatment study could be expanded to investigate the efficiency of different methods of fertilizer application, effect of the form of the phosphate carrier on the absorption of phosphorus by the plants could be evaluated, and the diffusion of phosphorus away from the fertilizer band with the resultant effect on the uptake of phosphorus by plants could be studied. The results showed that the greatest difference amongst the treatments was found when the width of the fertilizer band was changed. Therefore, the "width of the band" lead was expanded into the following experiment.

EXPERIMENT 5

In the last two experiments the phosphate fertilizer was applied as a narrow and a wide band. It was found that rape absorbed higher amounts of the fertilizer from a narrow band and soybeans absorbed larger amounts of the fertilizer from a wide band. The effect of widening the band on the uptake of fertilizer by flax and oats was not studied in that experiment.

Since the uptake of the fertilizer depended on the width of the band, it was thought reasonable to conduct an experiment to evaluate different methods of fertilizer application as to the availability of the added phosphate to the two crops used in the last experiment and to oats and flax. The four crops were selected for the reasons given in Experiment 2.

Materials and Methods

Treatments:- The fertilizer was applied as:

I. A "wide" band.

II. A "narrow" band

III. "Crystals spread"

IV. "Crystals centre".

Preparation of the radioactive fertilizer:- One mc P^{32} was received on October 14, 1964, and was diluted to one litre.

(a) Preparation of the radioactive solutions:

4.3942 gm KH_2PO_4 was dissolved in 500 ml (500 uc) of the P^{32} solution.

(i) 250 ml of this solution were taken out for treatment II.

(ii) The remaining 250 ml were diluted to one litre and used for treatment I.

(b) Preparation of radioactive crystals:

4.000 gm KH_2PO_4 was dissolved in a small volume of water in a polyethylene container and 500 ml (500 uc) P^{32} solution was added. The solution was mixed and evaporated to dryness on a sand bath. After evaporation, the radioactive KH_2PO_4 crust was transferred to a beaker and ground to between 0.10 and 0.25 mm diameter. These crystals were used for treatments III and IV.

Methods of fertilizer application:- The fertilizer was applied as a wide band in the first treatment and as a narrow band in the second treatment using solutions a(i) and a(ii), respectively. For the third treatment the P^{32}-tagged crystals were sprinkled as uniformly as possible over a smooth surface. In the fourth one, the same amount of crystals were placed in a small cavity in the soil at the centre of the pot so that phosphorus was available to the plants as a point source. In all the four treatments the fertilizer was about one-half inch below the seeds.

All the treatments were made in quadruplicate. The total number of ½-gallon pots used was 64. Each of the 64 pots received 20 mgm phosphorus. The amount of radioactive phosphorus supplied was 10 uc per pot in the first two treatments and 11 uc per pot in the last two treatments. Treatments I and II were seeded on October 15, 1964 and Treatments III and IV on October 17, 1964. Soybeans, rape, flax,and oats were harvested 60, 73, 82, and 60 days, respectively after seeding.

Results and Discussion

Data for the yield and percent phosphorus in the plant material are given in Table VIII. Although in soybeans, rape and flax, the yield was not affected on changing the method, there was a significant decrease in the yield of oats on applying phosphorus as crystals - the decrease being

TABLE VIII

WEIGHT OF OVEN-DRIED PLANT MATERIAL PER POT AND PERCENT PHOSPHORUS IN THE TISSUE AS AFFECTED BY METHOD OF APPLICATION

Crop		Solution		Crystals		LSD	
		40 ml	10 ml	Spread	Centre	0.05	0.01
Rape	Yield (gms)	5.41	5.22	5.35	5.36	NS#	NS
	Total P (%)	0.26	0.26	0.24	0.29	NS	NS
Oats	Yield (gms)	5.63	5.56	4.56	4.41	0.75	1.04
	Total P (%)	0.16	0.17	0.17	0.15	NS	NS
Soybeans	Yield (gms)	5.59	6.22	5.96	5.66	NS	NS
	Total P (%)	0.37	0.33	0.37	0.36	NS	NS
Flax	Yield (gms)	4.76	4.79	4.72	4.80	NS	NS
	Total P (%)	0.26	0.27	0.25	0.18	0.07	NS

NS = Not significant.

larger for the "crystals centre" treatment. At the 1% level, in oats, the wide band was significantly better than both methods of crystals application. The content of phosphorus was not significantly different from different applications in all the crops except in flax which showed a significant decrease from "crystals centre" application.

Table IX contains data to show the effect of widening the band on fertilizer uptake and total phosphorus absorbed. Statistical analysis showed that the amount of total phosphorus from four treatments was not different for soybeans and rape. The variation in other two crops is evident from the LSD values in the table. The total amount of phosphorus decreased in the order soybeans, rape, flax and oats.

As regards the percentage uptake of fertilizer, a narrow band is better than a wide band for rape but for the other crops the reverse is true. Phosphorus from the narrow band and the crystals spread was more or less equally available to all crops except oats, where the former method was found to be more efficient.

Rape absorbed more fertilizer from the crystals placed in the centre of the pot than from the uniformly spread crystals. But the other crops were more efficient in absorbing phosphorus from the crystals spread as compared to from the crystals centre. The absorption of phosphorus by soybeans from the fertilizer crystals applied in the centre

TABLE IX

TOTAL PHOSPHORUS (PER POT) AND PERCENT OF THE FERTILIZER ABSORBED

Crop		Solution		Crystals		LSD	
		40 ml	10 ml	Spread	Centre	0.05	0.01
Rape	Total P (mgm)	14.16	13.79	13.05	15.35	NS#	NS
	Uptake (%)	26.95	28.01	29.84	37.40	3.26	4.57
Oats	Total P (mgm)	9.03	9.33	7.54	6.57	1.60	2.24
	Uptake (%)	18.30	17.07	13.98	7.55	2.24	3.15
Soybeans	Total P (mgm)	20.60	20.21	22.28	19.87	NS	NS
	Uptake (%)	27.96	22.65	25.70	17.34	3.34	4.68
Flax	Total P (mgm)	12.45	12.81	11.80	8.56	2.38	3.33
	Uptake (%)	20.65	16.50	17.49	5.43	4.00	5.61

NS = Not significant.

of the pot was about two-thirds of that absorbed from the fertilizer crystals spread uniformly; the corresponding figures being about one-half and less than one-third for oats and flax respectively.

The soil employed in this experiment had a larger amount of available phosphorus than the soils used in the previous experiments (Table I). The uptake of soil phosphorus, as percent of the total phosphorus absorbed by the plants, in the present experiment was also higher than in the earlier experiments (Table X).

The differences in the amounts of soil phosphorus absorbed amongst the four treatments by any of the crops were statistically not significant. Under the conditions of the present experiment rape and flax were about equally efficient in extracting soil phosphorus. Soybeans and oats absorbed the largest and the smallest amounts of phosphorus from the soil, respectively.

Data in Table X show the variation in the ratio of soil phosphorus to fertilizer phosphorus in the plant. On narrowing the band, the "A" values decreased in rape and increased in the other crops. It is interesting to note that for rape and oats the "A" values were about equal in the first treatment but the values were much higher for oats in treatment IV. The "A" values being very high for soybeans, flax, and oats in treatment IV again show their greater

TABLE X

AMOUNT OF PHOSPHORUS (PER POT) ABSORBED FROM SOIL AND FERTILIZER AND "A" VALUE DATA

		Solution		Crystals		LSD	
		40 ml	10 ml	Spread	Centre	0.05	0.01
Rape	Fertilizer-P (mgm)	5.39	5.60	5.97	7.48	0.66	0.93
	Soil-P (mgm)	8.77	8.18	7.09	7.87	NS#	NS
	"A" value (ppm)	16.32	14.58	11.94	10.57	2.77	3.88
Oats	Fertilizer-P (mgm)	3.66	3.41	2.80	1.51	0.45	0.63
	Soil-P (mgm)	5.37	5.92	4.74	5.06	NS	NS
	"A" value (ppm)	14.66	17.32	16.93	34.80	6.95	9.75
Soybeans	Fertilizer-P (mgm)	5.59	4.53	5.14	3.47	0.67	0.94
	Soil-P (mgm)	15.00	15.68	17.14	16.40	NS	NS
	"A" value (ppm)	26.91	35.19	34.73	47.66	7.39	10.36
Flax	Fertilizer-P (mgm)	4.13	3.30	3.50	1.09	0.80	1.12
	Soil-P (mgm)	8.32	9.51	8.30	7.47	NS	NS
	"A" value (ppm)	20.62	29.03	23.64	68.61	5.93	8.31

NS = Not significant.

efficiency to absorb phosphorus from the soil when the fertilizer is present as a point source.

There was no distinct concentration of roots in the fertilizer band with soybeans, flax, and oats. By looking at the root distribution in the soil, it was very easy to locate the area where the fertilizer was applied in the case of rape. The concentration of roots was in a wider area in treatment I than in treatment II or III. Moreover there was a mass of roots in the centre of the pot in treatment IV. It is not clear whether the concentration of roots in the fertilizer zone is due to the higher uptake or it is the large amount of fertilizer absorption that gives rise to the abundance of the roots. There was an evidence of the fertilizer crystals present in a small amount in treatment IV of all the crops after the plants were harvested.

The roots of rape plants can concentrate in an area where the fertilizer phosphorus is present. It was observed that the root concentration was more distinct in a narrow band than in a wide band. Also, the total quantity of roots in the narrow band appeared to be more than in the wide band. This may be the reason why a narrow band is superior to a wide band in supplying the fertilizer and therefore it seems that the uptake of phosphorus by rape depends to some degree on the number of roots present in the fertilizer band. Thus it is clear that the uptake of the fertilizer by a crop depends on the method of application (32,61,107).

The roots of the other crops do not concentrate in the vicinity of the fertilizer zone. It appears that fertilizer uptake by these crops does not depend on the number of roots in the fertilizer band, except that in a wide area there will be more roots than in a narrow area.

The difference in phosphate uptake by the crops may be due to phosphate fixation in the soil and then the differential abilities of the plants to feed on these compounds. Phosphorus applied in a wide band is in contact with a large amount of soil. Application of the fertilizer in a narrow band diminishes the surface of contact between the fertilizer and the soil. The concentrated source of phosphorus applied as crystals is in contact with even less soil. Thus different amounts of phosphorus are fixed by the soil from the fertilizer applied by various methods.

Apparently rape is less efficient than soybeans in utilizing fixed phosphorus. Rape can absorb more phosphorus from the fertilizer crystals perhaps because less phosphorus is fixed compared to other methods of application. The results show that flax and oats behave like soybeans in the extraction of fixed phosphorus.

In general, for rape the narrower the band the higher is the fertilizer uptake. The opposite is true with the other crops. This supports the results of Blaser and McAuliffe (17) that the efficiency of a particular method depends on the type of the crop grown. The method of application is more important for flax and oats than for rape. It is suggested that a proper method must be selected for an efficient use of the fertilizer.

EXPERIMENT 6.

In the last experiment it was observed that the uptake of fertilizer depends on the method of application. A wide variation was found amongst the crops particularly where the crystals were placed in the centre of the pot. This observation led to the experiment described below.

The purpose of the experiment was to study the uptake of fertilizer as influenced by the pH and the solubility of the phosphate carrier. Two soils differing in the amount of $NaHCO_3$-extractable phosphorus were used and thus it was possible to evaluate the influence of soil phosphorus level on the utilization of the phosphate fertilizer.

In the first experiment it was found that buckwheat is a very good utilizer of the fertilizer. So this crop was used in place of soybeans in the present experiment to study its ability to absorb fertilizer and compare it particularly with that of rape.

Materials and Methods

The following treatments were included:-

I. Monopotassium phosphate (MKP) as "crystals spread".

II. Monopotassium phosphate (MKP) as "crystals centre".

III. Dicalcium phosphate dihydrate (DCPD) as "crystals centre".

IV. Dipotassium phosphate (DKP) as "crystals centre".

Soil I (high in available phosphorus) was used for all the four treatments. Soil II (low in available phosphorus) was used for the treatment in which MKP was applied as "crystals centre". Rape, flax, oats, and buckwheat were grown. The treatments were replicated four times. A total of 80 one-half gallon pots were required.

Two millicurie P^{32} was obtained in June 22, 1965. It was diluted to 100 ml. Only radioactive crystals were used in this experiment. MKP and DKP crystals were made radioactive in the same way as for treatments III and IV of the last experiment. DCPD* was prepared in the following way:

A phosphorus ($Na_2H\overset{*}{P}O_4 \cdot 2H_2O + KH_2\overset{*}{P}O_4$) solution and a $CaCl_2$ solution were added slowly to a MKP solution and stirred mechanically. The pH was maintained between 4 and 5 (6). The mother liquor was sucked from the crystals which were washed with a very dilute solution of H_3PO_4 and then with ethanol prior to air-drying. The content of P and Ca in the compound was 17.50% and 23.28%, respectively, which is very close to the theoretical values and thus indicates that the compound was successfully prepared.

For solubility studies, one-tenth of a gram of DCPD was shaken with 50 ml water for 24 hours. The pH of the suspension was measured. After filtering, Ca and P were determined in the filtrate using EDTA and colorimetric methods, respectively. The coordinates (pH-$\frac{1}{2}$pCa) and (pH_2PO_4 + $\frac{1}{2}$p Ca) were calculated from the following analytical data:

$$pH = 6.00$$

$$[P] = 0.316 \times 10^{-2}M$$

$$[Ca] = 0.163 \times 10^{-2}M$$

$$\frac{1}{2}\ p\ Ca = 1.47$$

$$pH_2PO_4 = 2.54$$

Thus,

$$(pH - \tfrac{1}{2}p\ Ca) = 6.00-1.47 = 4.53$$

$$(pH_2PO_4 + \tfrac{1}{2}p\ Ca) = 2.54+1.47 = 4.01$$

$$K = (pH - \tfrac{1}{2}p\ Ca)-(pH_2PO_4 + \tfrac{1}{2}p\ Ca) = 0.52 \text{ at } 25^{\circ}C$$

The value for K reported in the literature (90) is 0.66 at 18°C.

The fertilizer crystals supplied 20 mgm P per pot. Each pot received 10 uc P^{32} from MKP and DKP and 10.7 uc from DCPD crystals. The crops were seeded on June 27,1965, and harvested after a period of 60 days.

For the preparation of octacalcium phosphate (OCP) a phosphorus ($Na_2H^*PO_4$) solution and a $CaCl_2$ solution were added drop by drop to a beaker containing some water, and the mixture was stirred mechanically. The pH was maintained at 10 using 6N NaOH solution. The mother liquor was sucked and the crystals were washed rapidly three times with ethanol and then air-dried. The crystals were ground to between 0.10 and 0.25 mm diameter. The content of P and Ca in the compound was 15.40% and 30.32%, respectively, which is very close to the theoretical values and thus indicates that the compound was successfully prepared.

For solubility studies the following values were obtained:

$$\mathrm{pH} = 7.13$$
$$[\mathrm{P}] = 0.818 \times 10^{-3}\mathrm{M}$$
$$[\mathrm{Ca}] = 0.155 \times 10^{-3}\mathrm{M}$$
$$\tfrac{1}{2}\mathrm{p\ Ca} = 1.94$$
$$\mathrm{pH_2PO_4} = 3.37$$

Thus,

$$K = (\mathrm{pH}-\tfrac{1}{2}\mathrm{p\ Ca})-3\ (\mathrm{pH_2PO_4}+\tfrac{1}{2}\mathrm{p\ Ca}) = 10.03$$

The value for K reported in the literature (90) is 9.93.

The crops were grown on Soil I. P^{32}-labelled OCP was applied as "crystals centre" supplying 20 mgm P^{31} and 10 uc P^{32} per pot. Seeding was done on January 20, 1966. The crops were harvested 43 days after seeding.

Results and Discussion

Data for the yield, total phosphorus, and fertilizer uptake are summarized in Table XI. The dry matter produced on Soil I was higher than Soil II in all the four crops. The phosphorus content was higher in the plant material from Soil I than from Soil II in all the plants except in oats where the content did not decrease with a decrease in soil phosphorus level.

The comparison of crystals spread and crystals centre shows that the latter is slightly better for rape and buckwheat in their utilization of MKP. But in flax and oats the uptake is reduced to about one-sixth and one-third, respectively when the crystals are placed in the centre of the pot rather than spreading them. Webber (114) reported that flax responded to phosphate mixed throughout the soil but no response was obtained from band application. He also found that oats and rape responded to both mixed and band application.

The results show, as was shown in the last experiment, that the efficiency of a fertilizer depends on the method of application (32,61,107).

The table shows that MKP and DKP are more or less equally available to rape or buckwheat. But flax and oats absorbed phosphorus about four and two times, respectively,

TABLE XI

WEIGHT OF THE PLANT MATERIAL (PER POT), PERCENT PHOSPHORUS IN THE TISSUE, AND PERCENT UPTAKE OF THE FERTILIZER

Crop		Soil I				Soil II
		Crystal Spread	Crystal Centre			
		MKP#	MKP#	DCPD##	DKP###	MKP#
Buckwheat	Yield (gm)	17.76	16.62	16.44	17.12	15.61
	Total P (%)	0.16	0.15	0.16	0.15	0.12
	Uptake (%)	55.39	57.54	42.45	55.54	53.85
Rape	Yield (gm)	10.25	10.11	10.00	10.39	9.13
	Total P (%)	0.23	0.23	0.22	0.23	0.18
	Uptake (%)	49.10	50.01	38.25	52.19	56.93
Oats	Yield (gm)	10.19	9.69	8.80	10.22	6.04
	Total P (%)	0.19	0.18	0.19	0.18	0.18
	Uptake (%)	29.24	10.58	6.69	20.54	13.40
Flax	Yield (gm)	6.12	6.53	6.06	6.84	5.33
	Total P (%)	0.24	0.18	0.19	0.20	0.13
	Uptake (%)	19.13	3.15	1.46	11.64	5.15

MKP = Monopotassium phosphate.

DCPD = Dicalcium phosphate dihydrate.

DKP = Dipotassium phosphate.

from DKP as that absorbed from MKP. The results show that the efficiency of a particular method is also determined by the availability of the fertilizer (85).

The higher availability of DKP is possibly due to its diffusion in a larger area around the crystal zone. Uptake of phosphorus from DCPD crystals is of particular interest. Rape and buckwheat absorbed about 40% of the phosphorus in this carrier while flax and oats absorbed only 1.5% and 6.7%, respectively. DCPD was always less available than the other two carriers tested. Rape and buckwheat are almost similar in efficiency to pick up phosphorus irrespective of the carrier used for making crystals. Oats were found to be less efficient than these two crops. Flax was least efficient in absorbing phosphorus from the crystals.

The effect of soil phosphorus level on the utilization of MKP, applied as crystals centre is also shown in Table XI. Rape, flax, and oats absorbed more fertilizer from a soil low in available phosphorus. The results corroborate the findings of Bureau et al. (25), Jacob et al. (57), and Woltz et al. (117). However, there was some decrease in fertilizer utilization by the buckwheat plants on the soil low in available phosphorus. Generally, the results fall in line with the observations of several workers (75,103) that the influence of fertilizer placement depends on the soil being used.

Data presented in Table XII show that the amount of total phosphorus absorbed by the plants decreased in the order buckwheat > rape > oats > flax. The comparison on two soils for the uptake of phosphorus from MKP crystals confirms the observations of Woltz et al. (120) that an increase in the soil phosphorus level increases total growth, and total phosphorus uptake but decreases the percentage of fertilizer phosphorus in the plant.

Less phosphorus was absorbed by the plants from Soil II because of the limited quantity of available phosphorus present in the soil. A comparison of the MKP crystals spread and crystals centre treatments on Soil I shows that the fraction of total phosphorus absorbed from the soil was higher for rape and buckwheat from the crystals spread treatment and for oats and flax from the crystals centre treatment (Table XII). The plants absorbed more soil phosphorus from the treatment where DCPD was used because of the lower uptake from this compound as compared to the other phosphorus sources used.

The soil phosphorus to fertilizer phosphorus ratios in the plants are given in Table XII. On changing the method of application from crystals spread to crystals centre the "A" values decreased somewhat in rape and buckwheat but increased significantly in the other two crops. "A" values were higher in plants grown on phosphorus rich soil. In

TABLE XII

PHOSPHORUS UTILIZATION (PER POT) AND "A" VALUES

		Soil I				Soil II
		Crystal Spread	Crystal Centre			
		MKP#	MKP#	DCPD##	DKP###	MKP#
Buckwheat	Total P (mgm)	27.63	24.86	25.56	26.19	18.81
	Fertilizer-P (mgm)	11.08	11.51	8.49	11.11	10.77
	Soil-P (mgm)	16.55	13.35	17.07	15.08	8.04
	"A" value (ppm)	15.08	11.85	20.56	13.58	7.52
Rape	Total P (mgm)	23.39	23.48	21.98	24.31	16.81
	Fertilizer-P (mgm)	9.82	10.00	7.65	10.44	11.39
	Soil-P (mgm)	13.57	13.48	14.33	13.87	5.42
	"A" value (ppm)	13.86	13.52	18.91	13.38	4.74
Oats	Total P (mgm)	19.10	17.16	16.72	18.55	10.76
	Fertilizer-P (mgm)	5.85	2.12	1.34	4.11	2.68
	Soil-P (mgm)	13.25	15.04	15.38	14.44	8.07
	"A" value (ppm)	22.71	72.79	117.69	35.36	30.29
Flax	Total P (mgm)	14.96	11.46	11.67	13.51	6.84
	Fertilizer-P (mgm)	3.83	0.63	0.29	2.33	1.03
	Soil-P (mgm)	11.14	10.83	11.38	11.18	5.81
	"A" value (ppm)	29.26	192.95	427.61	48.54	57.89

\# MKP = Monopotassium phosphate.
\## DCPD = Dicalcium phosphate dihydrate.
\### DKP = Dipotassium phosphate.

general, the "A" values decreased in the order flax $>$ oats $>$ buckwheat $>$ rape.

Root studies showed that in crystals spread there was a distinct root concentration in the band with rape but not with the other crops. No crystals were found in any pot. In MKP crystals centre a very good concentration of roots was found around the crystals with rape. There was no such root concentration with flax and oats but buckwheat showed some concentration. Only traces of the crystals were present in the centre of all the pots. Root concentration with rape was in a slightly wider area in the soil low in available phosphorus.

In most of the pots the DCPD crystals were present apparently in almost the same quantity in which they were placed. However, it appeared that in rape the carrier had slightly moved. The crystals were present in a loose form in flax and oats but as a solid mass in buckwheat; in rape the form was somewhere in between the other two forms. There was a distinct root concentration around the crystals with rape but none whatsoever with the other crops.

A very insoluble source of phosphorus, such as OCP, was used with the view that this might show some differences in the absorption capacity of rape and buckwheat and also show the ability of flax and oats to extract phosphorus from this carrier. Rape, flax, oats, and buckwheat absorbed

20.09, 0.76, 0.81 and 19.48% of the phosphorus present in OCP. This again shows that rape and buckwheat are about equally efficient in absorbing the added phosphorus and flax and oats are inefficient in extracting phosphorus from an insoluble carrier.

EXPERIMENT 7

Studies conducted so far showed the differential ability of plants for phosphorus uptake on calcareous soils. The efficiency of a particular method of fertilizer application has been reported to be different for acid and alkaline soils (103).

The following experiment was conducted on a non-calcareous soil. The objective of this experiment was to investigate whether the differences manifested on calcareous soils are also shown on non-calcareous soils.

Materials and Methods

The seeds of rape, flax, wheat, and buckwheat were planted on January 4, 1966. Radioactive monopotassium phosphate (MKP) crystals were applied as "crystals spread" and "crystals centre". The treatment combinations were triplicated. Twenty four ½-gallon pots were required. The above-ground portions were harvested 52 days after seeding.

Results and Discussion

The soil used for the present experiment was high in the amount of $NaHCO_3$-extractable phosphorus as compared to the calcareous soils used (Table I).

Table XIII contains the results of this experiment.

The "t" test showed that the plant yields from the two methods of applying phosphorus were statistically not different.

In view of the data presented in Table XI for a calcareous soil and in Table XIII for a non-calcareous soil it is clear that the efficiency of two methods of crystal application depends, besides other factors, on the presence of calcium carbonate. Phosphorus from the "crystals centre" was more available than from "crystals spread", to rape and buckwheat in the calcareous soil but the opposite was found in the non-calcareous soil. In the case of flax and a cereal, phosphorus from the "crystals centre" was more available in the non-calcareous than in the calcareous soil. Although there was a larger uptake of fertilizer from the "crystals spread" than from the "crystals centre" in all crops, this difference was statistically significant only in flax.

In the previous experiment it was found that the fertilizer absorption decreased to one-sixth for flax and one-third for oats when the method was changed for applying MKP

TABLE XIII

PHOSPHORUS UTILIZATION AND "A" VALUE DATA ON A NON-CALCAREOUS SOIL

	Yield (gm/pot)			Fertilizer uptake (%)			Soil-P uptake (mgm/pot)			"A" value (ppm)		
	I	II	Difference	I	II	Difference	I	II	Difference	I	II	Difference
Buckwheat	5.97	6.17	0.20	37.75	24.17	13.58	8.79	9.74	0.95	11.64	22.08	10.44
Rape	4.10	3.96	0.14	27.24	24.63	2.61	8.36	8.21	0.15	15.41	16.69	1.28
Wheat	3.06	3.10	0.04	17.33	14.19	3.14	4.05	5.64	1.59	11.70	19.93	8.23#
Flax	1.87	2.01	0.14	9.09	4.98	4.11#	2.92	3.61	0.69	16.32	37.12	20.80#

I Crystals spread

II Crystals centre.

Significant at 5% level.

crystals from "crystals spread" to "crystals centre". A decrease in fertilizer uptake by flax and wheat was found in the non-calcareous soil but it was not as large as in the calcareous soil.

Esau and Racz[1] found that the uptake of phosphate fertilizer by flax increased with an increase in the area of fertilizer placement, particularly so on the calcareous soil. They observed that the "crystals centre" was much better than the "crystals spread" for rape on the calcareous soil but the former was somewhat less efficient than the latter method in supplying phosphorus to these plants on the non-calcareous soil. The amount of available phosphorus in calcareous and non-calcareous soil was 7.29 and 7.99 ppm, respectively. Therefore, the differences in the abilities of the plants to extract phosphorus from the fertilizer crystals are present between calcareous and non-calcareous soils although the phosphorus level of both the soils is similar. Their results are in line with the findings reported here.

The amounts of phosphorus absorbed from the soil were not significantly different from the two methods of fertilizer application for any of the crops used.

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[1]Esau, R. and G.J. Racz. 1966. Unpublished data, Department of Soil Science, University of Manitoba.

The "A" values were high for the "crystals centre" treatment for all the crops, but these differences were significant only for flax and wheat. The "A" values for rape and flax were almost similar in the "crystals spread" treatment but from the other treatment these values for flax were about twice as high as that for rape. Because the soil phosphorus uptake by flax, like other crops, was not different for the two methods of application, a very high "A" value for the "crystals centre" treatment of flax is due to its much lower uptake of the fertilizer from the crystals placed in the centre of the pot than that from the crystals spread uniformly.

Thus it is evident that the availability of phosphorus from the fertilizer applied by a particular method is different for calcareous and non-calcareous soils.

C. BOX EXPERIMENTS

The results of the previous experiments showed the differential phosphate feeding abilities of the plants when the fertilizer was accessible to all the roots. These differences amongst the plants could be due to the difference in the efficiency of a single root to solubilize the phosphates before absorption or due to the difference in the capacity of translocating the absorbed phosphates to other parts of the plants. Thus the approach in the following two experiments was to use a split-root technique in which the fertilizer phosphorus was available to a single root and the soil phosphorus was available to all the roots.

Materials and Methods.

Four growth boxes were used. They were constructed from plexiglass (a transparent plastic material) and were painted with a black paint on the outside. The box had a removable front so that the distribution of roots could be seen. The box was divided into two parts and each of them served as one replication. Each part in turn was divided into two compartments - the back compartment for growing the plant and the front one for growing the single root. The design of the box was obtained from Dr. M. H. Miller (personal communication). A drawing of such a box is given in Figure 12.

Rape, flax, oats, and buckwheat were grown. One box was used for each crop. Each of the back compartments contained 7.5 kg and each of the front compartments contained 3.6 kg of the air-dried soil. Moist soil was placed in the boxes. The seeds were germinated in vermiculite. A complete nutrient solution was prepared (73). The solution was diluted to one-half the concentration and added to vermiculite at proper intervals after germination.

Two plants were grown in a box, i.e., one plant in

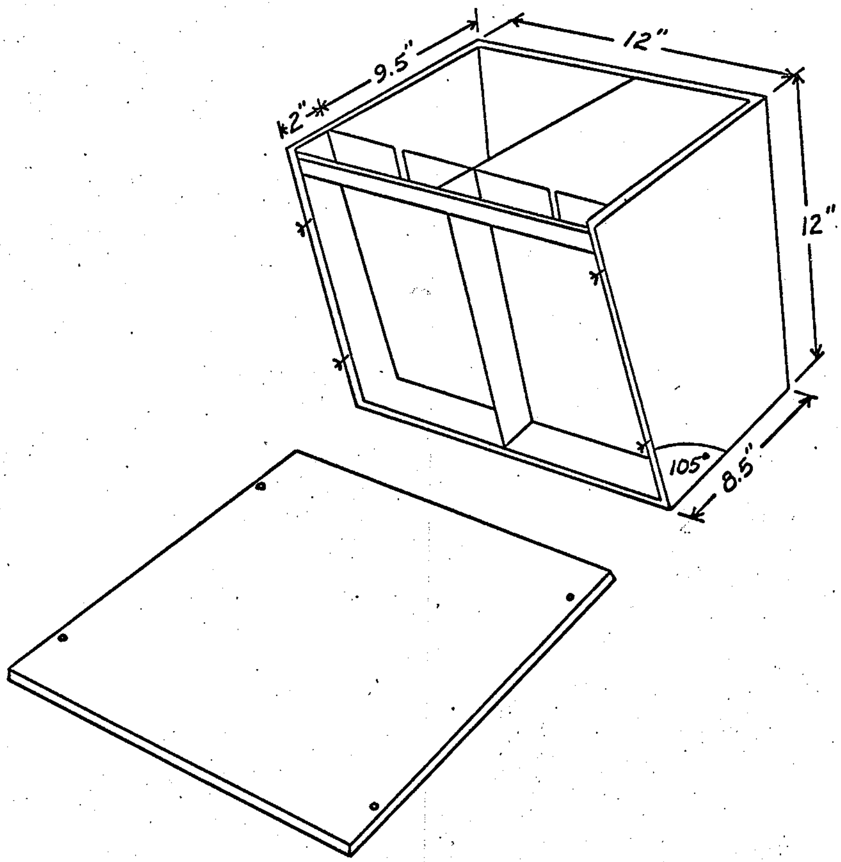

Figure 12. A Drawing of The Box Used to Study Phosphorus Uptake by a Single Root

each of the back compartments. A single root was passed through the slot in the plexiglass divider to the front compartment at the time of transplanting. Radioactive monopotassium phosphate (MKP) crystals were used. The plants were watered periodically as in the pot experiments. Wire supports were provided. The leaves that fell off from the plants were collected.

EXPERIMENT 1

Materials and Methods

The seeds were sown in vermiculite on July 6, 1965 and watered whenever required. A complete nutrient solution was then added periodically.

The plants were transplanted into the back compartments 23 days after seeding. A single root of the plant was passed through the slot in the plexiglass divider to the front compartment to let it grow against the front wall. In buckwheat the primary root was passed through the slot and in the other three crops the secondary roots were passed to the front compartment.

Ten days after transplanting, the radioactive fertilizer crystals supplying 20 mgm P^{31} and 10 uc P^{32} were placed in each of the front compartments close to the single root near the centre of the front wall. No other nutrients were added because the plants were being grown in a large amount of soil. The crops were harvested on September 20, 1965 and analyses were done.

Results and Discussion

The results of this experiment are shown in Table XIV. The data presented are averages of the duplicates for rape and buckwheat and are individual values for the other two crops.

Rape produced more dry matter than buckwheat. The yield of flax was only one-third and less than one-tenth of that obtained from oats and rape, respectively. The phosphorus content in the plant material of flax was much higher than in the other crops. The amount of total phosphorus absorbed by the plants decreased in the order rape, buckwheat, oats, and flax. The amount of soil phosphorus absorbed per gram of plant material was highest for flax but rape absorbed the largest amount of soil phosphorus.

The single root of both plants of oats and one plant each of flax and buckwheat died a few days after transplantation. Therefore, it was not possible to determine fertilizer uptake by oats. The single root of rape absorbed and translocated 24.00% of the fertilizer. The corresponding figures for buckwheat and flax were 4.96% and 0.27%, respectively.

TABLE XIV

WEIGHT OF THE OVEN-DRIED PLANT MATERIAL AND PHOSPHORUS UTILIZATION IN EACH COMPARTMENT.

	Buckwheat##	Rape#	Oats#	Flax##
Yield (gm)	12.11	14.51	3.74	1.25
P in tissue (%)	0.31	0.38	0.33	0.68
Uptake (%)	4.96	24.00	-	0.27
Total P (mgm)	37.30	55.70	12.49	8.45
Fertilizer-P (mgm)	0.99	4.80	-	0.05
Soil - P (mgm)	36.31	50.91	-	8.40

Average of two replications

Results of one replication.

This study very well confirms the results obtained in the previous experiments that rape is very efficient in absorbing large amounts of phosphorus from a concentrated source while flax is least efficient in absorbing the fertilizer from such a high phosphate concentration. It appears that the single root of rape can solubilize and translocate phosphorus in large amounts to other parts of the plant. Flax does not seem to have either one or both of these characteristics. In the previous experiments buckwheat has always been found to be as good or better than rape in extracting added phosphorus. However, the single root of buckwheat absorbed only small amounts of the fertilizer under the present experimental conditions.

The slight angle of the front kept the root growing at the soil surface. The growth pattern of the single root was observed periodically by taking off the removable front. A distinct concentration of roots was found with rape where the phosphate carrier was applied. This indicates that the single root of rape branches out profusely on coming in contact with the fertilizer and, therefore, a distinct concentration of roots found in the fertilizer band in the pot experiments seems to be due to this characteristic. No such root concentration was present with flax and buckwheat. It appears that a single root of flax and buckwheat does not branch out to give a distinct root concentration. Because the primary root of buckwheat was passed through the slot, this observation can not be generalized for other roots as well. Therefore, it was thought appropriate to let the plants grow for a little longer period of time before transplanting so that the secondary root of buckwheat could be passed through the slot.

EXPERIMENT 2

Materials and Methods

The procedure was the same as that for the last experiment except that:

(1) Seeding in vermiculite was done on December 7, 1965.

(2) Transplanting into the boxes was done 35 days after seeding, so the plants were older than in the previous experiment and thus it was possible to put the secondary root of buckwheat also through the slot in the divider.

(3) The radioactive fertilizer crystals were placed at transplanting time.

(4) The crops were harvested on March 7, 1966.

Results and Discussion

Plant yield and phosphorus utilization data are shown in Table XV. In rape, flax, and oats the values presented

TABLE XV

WEIGHT OF THE OVEN-DRIED PLANT MATERIAL IN EACH COMPARTMENT AND PHOSPHORUS UTILIZATION DATA#

	Buckwheat### I	Buckwheat### II	Rape##	Oats##	Flax##
Yield (gm)	8.37	10.26	18.89	10.42	2.61
P in tissue (%)	0.36	1.23	0.24	0.24	0.50
Uptake (%)	1.79	29.83	19.38	0.34	0.36
Total P (mgm)	30.30	125.69	45.26	24.89	12.98
Fertilizer-P (mgm)	0.36	5.97	3.88	0.07	0.07
Soil-P (mgm)	29.94	119.72	41.38	24.82	12.91

At the time of transplanting each plant of rape, flax, oats, and buckwheat contained 1.96, 0.85, 2.20 and 9.57 mgm P, respectively.

Average of two replications.

Results of the two replications are given separately.

are the averages for two replications. Due to a large difference in the phosphorus utilization data obtained from the duplicates of buckwheat, the values from each replication have been given separately. The yields of rape, flax, and oats were much higher than in the previous experiment although buckwheat produced somewhat less plant matter.

In rape, a distinct concentration of roots was found near the area of fertilizer application. Flax and oats did not show any such concentration. Buckwheat did show some root concentration where the crystals were applied in second replication.

Rape produced a distinct concentration of roots in the vicinity of the fertilizer and thus used it efficiently by solubilizing and translocating absorbed phosphorus to other parts of the plant. The data show that both flax and oats are very poor in solubilizing and/or translocating phosphorus to the other parts of the plant.

The single root of buckwheat in the first replication absorbed only one-eleventh of the fertilizer of that absorbed by rape but from the second replication absorbed one-and-a-half times of that absorbed by rape. This difference between the two treatments of buckwheat can be explained by the fact that there was a better root concentration in the fertilized area in the second replication. It is also clear that a single root of buckwheat can absorb the fertilizer in quantities higher or lower than that absorbed by rape and this seems to depend on the root concentration in the vicinity of the fertilizer. The higher uptake of the fertilizer by buckwheat in the second replication was reflected in the yield.

The amount of soil phosphorus absorbed by rape was higher than that absorbed by flax and oats. The higher content of fertilizer phosphorus seems to have encouraged root growth and this probably increased the uptake of soil phosphorus in the second replication of buckwheat. However, this does not seem to account for all the extra soil phosphorus absorbed. There is a possibility that the higher amount of soil phosphorus absorbed in the second replication is due to a contamination in the determination of total phosphorus.

These box experiments show that the differences in the plants in the abilities to absorb fertilizer phosphorus are due to the difference in their efficiency to solubilize and translocate phosphorus. Which one of these factors, that of solubilizing the phosphates or that of translocating absorbed phosphorus, is more important can be studied by eliminating one of these factors.

CHAPTER V

HYDROPONIC EXPERIMENTS

In the split root technique using plexiglass boxes it was found that a single root of flax and oats was not able to absorb phosphorus from a very concentrated zone while that of rape was quite efficient. The single root of buckwheat did not absorb sufficient quantities of the fertilizer when the root did not branch in the fertilized area but did absorb large quantities of the added phosphorus when there was some branching of the root in the vicinity of the fertilizer zone.

The box experiments showed that the efficiency of a single root of the plant to utilize the fertilizer seems to be due to its ability to solubilize or translocate phosphorus or due to both these reasons. By using nutrient solutions one of these factors - that of solubilizing - can be eliminated and the difference in the abilities of the plants to translocate phosphorus can be studied. So it was thought desirable to conduct some nutrient culture experiments.

Two nutrient culture experiments were conducted in which the split root technique was used. The purpose of the experiments reported was to study the efficiency of a single root to absorb and translocate phosphorus to the tops and rest of the roots. Moreover, studies were also done to find the effect of other nutrients on the root growth and uptake characteristics. The single root was subjected to one solution and the rest of the roots to another.

A. MATERIALS AND METHODS

Rape, flax, oats, and buckwheat were seeded in vermiculite and the nutrients were applied at frequent intervals, as described for the box experiments. The plants were transplanted into the jars.

Aluminum-foil was wrapped around jars to shroud the nutrient solutions from the light and thus prevent undesirable effects. The tops of the jars were made waterproof by coating them with paraffin. Two compartments were made in each jar by putting a polyethylene tube in it. The cover of each jar had three holes, one of them being for the plant and the other two for glass tubes for aeration, supplying air in the solutions of the jar and of the tube. The glass tubes were connected to plastic tubes which were in turn connected to a compressed air line for aeration. Air was bubbled slowly through the solutions to maintain aerobic conditions to support proper plant growth. The experiments included three treatments. There were three replications. A total of 36 one-pint jars were used.

The nutrient solutions were prepared as described by Machlis and Torrey (73). The solution contained major salts in the following concentrations: $Ca(NO_3)_2$, 5.0 mM; KNO_3, 5.0 mM, and $MgSO_4$- 2.0 mM. The solution was 5 ppm with respect to iron supplied as FeEDTA. The concentration of the micronutrients was the same as given in the procedure (73).

The volumes of the solutions used for the jar and the tube were 300 and 40 ml, respectively. The solutions were shaken thoroughly before using them. The stock solution of phosphorus was prepared by mixing 1 M KH_2PO_4 and 1 M K_2HPO_4 such that the pH of the solution was the same as that of the complete minus phosphorus solution (pH = 5.4).

One plant was grown in each jar. Vermiculite adhering to the roots was carefully removed by washing in water before transplanting. The stems were supported by placing small wads of cotton around them. The plants were kept in an upright position by wire support.

After growing in the nutrient solutions, the plants were removed and the roots were washed thoroughly. The shoots and roots were excised, dried, and analysed separately.

The first of the two chemiculture experiments was carried out without the use of radioactive phosphorus.

EXPERIMENT 1

Materials and Methods

The seeding in vermiculite was done on April 15,1965, and the complete nutrient solution was supplied in the same manner as in box experiments.

The following treatments were included:

I. A 93.0 ppm phosphorus solution in the tube and a complete minus phosphorus solution in the jar.

II. Water in the tube and a complete solution containing 12.4 ppm phosphorus in the jar.

III. A complete solution containing 93 ppm phosphorus in the tube and a complete minus phosphorus solution in the jar.

Transplanting into the jars was done on May 18, 1966. A single secondary root of all the plants were passed into the tubes. Flax plants seemed to have some nutrient deficiency at the time of transplanting which, however, disappeared later on.

The solutions were changed once every week. The volume of the solution was maintained by adding water every second day during the first week and then every day. Besides a fresh supply of nutrients at the time of transplanting, the nutrients were changed five times during the period when the plants grew in the jars. Thus each plant was subjected to a total of 22.32 mgm phosphorus. The flax plant in the second replication of treatment II died two weeks after transplanting and therefore the results given in the tables for this treatment are the average of the remaining two replications. The crops were harvested 36 days after transplanting. The roots were washed thoroughly.

The roots and shoots were excised, dried, and analyzed separately.

Results and Discussion

Visual observations showed that the plants of treatment II were growing best. Treatment I was slightly better than treatment III for flax but for the other three crops treatment III was better than treatment I.

The single root of rape, oats, and buckwheat absorbed phosphorus from solutions of high concentrations used in this experiment (Table XVI) provided that other nutrients were also present for proper root growth. The high phosphorus concentration in the nutrient media was detrimental to a flax root.

The single root in treatments I and II did not branch in any of the plants. The presence of other nutrients had a favourable effect on the growth and branching of the single root and this effect was very prominent in rape. At the time of transplanting the volume of a single root was largest in oats, followed by buckwheat, rape, and flax. The weights of the single roots after growing the plants in the nutrient solutions are recorded in Table XVII. The uptake of phosphorus varied with the weight of the single root.

A single root of rape in the presence of other nutrients

TABLE XVI

THE YIELD OF OVEN-DRIED PLANT MATERIAL AND PHOSPHORUS UTILIZATION DATA PER PLANT AFTER GROWING IN NUTRIENT SOLUTIONS

Crop	Treatment#	Yield (gm) Tops	Yield (gm) Roots	Total## P (mgm) Tops	Total## P (mgm) Roots	P in tissue (%) Tops	P in tissue (%) Roots	P absorbed from the solution (%)
Buckwheat	I	2.49	0.40	4.21	0.76	0.17	0.19	4.61
	II	3.93	0.56	18.68	2.17	0.47	0.39	75.76
	III	3.55	0.61	7.62	1.16	0.21	0.18	21.68
Rape	I	2.24	0.39	2.20	0.74	0.10	0.18	0.18
	II	5.42	0.73	13.65	3.80	0.25	0.53	65.18
	III	3.98	0.59	10.20	2.49	0.26	0.42	43.86
Oats	I	1.32	0.16	2.68	0.21	0.20	0.14	3.49
	II	2.27	0.26	12.80	2.72	0.57	1.05	60.08
	III	1.61	0.18	3.40	0.41	0.21	0.24	7.62
Flax	I	0.15	0.08	0.13	0.07	0.11	0.09	0.00
	II	0.54	0.10	3.82	0.99	0.73	0.99	20.65
	III	0.10	0.05	0.15	0.05	0.15	0.12	0.00

\# Treatment :
- I. 93.0 ppm P solution in tube and complete minus P solution in jar.
- II. Water in tube and complete solution containing 12.4 ppm P in jar.
- III. Complete solution containing 93 ppm P in tube and complete minus P solution in jar.

\## Phosphorus content of each plant at transplanting in rape, flax, oats and buckwheat was 2.51, 0.16, 1.96, and 3.69 mgm in tops and 0.39, 0.04, 0.15, and 0.25 mgm in roots, respectively.

TABLE XVII

WEIGHT OF THE SINGLE ROOT (IN GRAMS) AFTER GROWING THE PLANTS IN THE NUTRIENT SOLUTIONS

Crop	Treatment#		
	I	II	III
Buckwheat	0.015	0.011	0.017
Rape	0.004	0.006	0.072
Oats	0.006	0.007	0.007
Flax	0.003	0.002	0.007

See footnote of Table XVI

absorbed two-thirds of the phosphorus absorbed by all the roots. The single roots of other crops were much less efficient and a single root of flax did not absorb at all from this solution containing 93.0 ppm phosphorus. In the absence of other nutrients in the solutions, a single root of rape was less efficient than oats and buckwheat but the presence of other nutrients increased the root growth of rape more than other crops and it absorbed the highest amounts of phosphorus.

Although in the presence of other nutrients a single root of rape absorbed the maximum amount of phosphorus, a single root of oats was most efficient in this respect on a per gram basis (Table XVIII). Thus the efficiency of a single root of rape to absorb phosphorus is due to its larger root size. Therefore, it can be concluded that in the presence or absence of other nutrients the uptake of phosphorus by a single root of the crops studied is dependent on the extent of root growth.

EXPERIMENT 2

The last experiment showed that the uptake of phosphorus by a single root was related to the extent of root development which in turn depends to a large extent on the presence of other nutrients. Thus it was thought appropriate to conduct a short-term absorption experiment

TABLE XVIII

UPTAKE OF PHOSPHORUS BY A SINGLE ROOT

Treatment# Crop		Weight of the root (gm)	P Uptake by single root (mgm)	P Uptake (mgm P/gm root)
Buckwheat	I	0.015	1.03	69
	III	0.017	4.84	285
Rape	I	0.004	0.04	10
	III	0.072	9.79	136
Oats	I	0.006	0.78	130
	III	0.007	1.70	243
Flax	I	0.003	0.00	0
	III	0.007	0.00	0

See footnote of Table XVI

with the use of radioactive phosphorus so that its translocation to the aerial parts and rest of the roots could be traced. It was thought desirable to study if these differences become pronounced at some particular stage of growth.

Materials and Methods

The seeds were planted in vermiculite on three different dates, 21, 35, and 45 days before transplanting. A complete minus phosphorus solution was used for the jars and a 93.0 ppm phosphorus solution was used for the tubes. The plants were transferred to the test media on July 11, 1966. They were allowed to adjust for three days to these conditions.

After the adjustment period, the solutions were changed. This time 30 ml of a 124.0 ppm phosphorus solution were used for the tube so that after the addition of 10 ml radioactive solution (10 uc P^{32}) the total volume in the tube became 40 ml with a concentration of 93.0 ppm phosphorus. The solutions were not aerated after the addition of P^{32} in order to avoid contamination of the solution in the jar by splashing of the radioactive solution from the tube.

The plants were harvested 24 hours after the addition of radioactive solution. The roots were washed thoroughly and the washings were saved with the nutrient media. The radioactivity was measured in the solutions and the plants to account for all the P^{32} added.

Results and Discussion

The amount of dry matter produced is shown in Table XIX. The weight of flax plants growing in vermiculite did not differ at the three different stages which may be due to the presence of some element(s) in quantities insufficient for optimum growth of the flax plants although a complete solution was used when the plants were growing in vermiculite. However, at the first stage buckwheat, rape, and oats produced only 1/10, 1/5 and 1/9, respectively of the dry matter produced at the second stage. The differences between the yields at first and second stages were much larger than between second and third stages because of the sigmoid growth curves of the plants.

A direct comparison between the previous and the present experiment is difficult because the plants were harvested 69 days after seeding in the last experiment and 25, 39, and 49 days after seeding for the present experiment. However, the results of the first treatment of the last experiment can be compared to some extent with the results of the present experiment because of the similarity in the treatment.

TABLE XIX

WEIGHT OF THE OVEN-DRIED PLANT MATERIAL (PER PLANT) AND THE RELATIVE COUNTS IN THE SOLUTIONS AND THE PLANT MATERIAL AFTER A SHORT-TERM EXPERIMENT.

Stage#		Yield (gm)		Counts per minute##			
		Tops	Roots	Tops	Roots	Solution in jar	Solution in tube
Buckwheat	I	0.34	0.04	15	19	5	100,787
	II	3.41	0.31	1,347	463	42	97,586
	III	3.64	0.38	442	53	286	99,858
Rape	I	0.09	0.01	55	15	9	99,361
	II	0.45	0.07	28	20	20	99,691
	III	0.59	0.14	5	208	9	99,117
Oats	I	0.09	0.03	571	475	826	98,807
	II	0.87	0.17	1,239	287	724	97,634
	III	1.00	0.24	45	429	1,376	98,956
Flax	I	0.06	0.01	50	55	71	100,030
	II	0.05	0.02	16	5	0	98,939
	III	0.06	0.02	3	12	2	101,592

\## Counts of the standard solution = 100,000

\# I 25 days after seeding
II 39 " " "
III 49 " " "

The fate of P^{32} added to the solutions in the tubes can also be seen in Table XIX. The last experiment showed that in the absence of other nutrients a single root of buckwheat absorbed more phosphorus than the other crops. The use of P^{32} in the present experiment showed that a similar trend was found when the plants were harvested 39 days after seeding. Thus the age of a plant has an important bearing on the relative uptake and translocation of phosphorus. At the last two stages most of the phosphorus was translocated to the tops while at the first stage the total amount of P^{32} translocated to the tops was not much different than that translocated to the roots.

A single root of rape in the absence of other nutrients was not efficient as only 0.18% of the phosphorus present in the nutrient media was absorbed in the last experiment. In the present experiment also rape did not show any efficiency in extracting phosphorus by a single root when no other nutrients were present because not more than 0.21% of the phosphorus was absorbed and translocated at any stage. The translocation of phosphorus to the tops decreased and towards the roots increased as the plants grew older.

In oats, at the first stage the translocation of phosphorus towards the roots was not much less than that towards the tops. At the second stage the plants absorbed more phosphorus than at any other stage and most of it was translocated to the tops. On the contrary, a very small amount of the absorbed phosphorus was translocated to the tops at the last stage.

The data indicate that a single root of flax can not absorb and translocate phosphorus from the concentration used in this experiment although it is somewhat active in absorption at the first stage. There is a continuous decrease in phosphorus uptake with the age of the plant. The single root of flax in older plants did not absorb phosphorus from a concentrated solution and whatever small amount is absorbed is translocated mainly to the rest of the roots. The single roots of other three crops are more active in absorbing phosphorus at some later date.

It is apparent that these crops differ in the efficiency with which a single root can absorb phosphorus from the solution. In addition, the fraction of total phosphorus translocated to the tops or the rest of the roots depends on the stage of plant development and varies with the crop.

It is concluded that a single root of buckwheat absorbs and translocates more phosphorus than does a single root of rape when other nutrients are not present. On the other hand, a single root of flax can not absorb phosphorus when its concentration is high in the nutrient medium irrespective of whether the other nutrients are present or not.

A single root of oats is more efficient than rape and flax when other nutrients are not present but is less efficient than rape and buckwheat in absorbing phosphorus when other nutrients are present.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The differential phosphate feeding abilities of mustard, rape, wheat, oats, barley, flax, peas, sunflowers, soybeans, corn, and buckwheat were studied. It was found that the crops differed widely in the amount of phosphorus absorbed from soil and from fertilizer and in their "A" values. Rape and mustard showed the greatest response to the added phosphorus. Flax did not show a response to the fertilizer although the soil was low in available phosphorus.

There was a distinct concentration of roots in the phosphate band with rape and mustard and these crops were very efficient in utilizing the fertilizer. From this one might conclude that a higher uptake of fertilizer phosphorus is necessarily correlated with a high root concentration in the band. Buckwheat also made efficient use of the fertilizer but, like other crops, did not show a distinct root concentration in the fertilizer band. It was concluded that a lack of root concentration in the fertilizer zone does not necessarily mean that the crop is not an efficient extractor of the fertilizer. Of course, the greater number of roots present in the band in rape and mustard may be helpful in the assimilation of the phosphate fertilizer.

An experiment was designed to find whether these differences amongst the crops are present throughout the growing season or they are at some particular stage of development. This was achieved by harvesting soybeans, rape, flax, and oats at seven different stages of growth. It was found that the crops differed throughout the growing season in the amounts of dry matter produced and in their phosphate feeding characteristics. There was a large difference amongst these crops in the production of dry matter at early stages but the amounts produced at the later stages were not much different.

In general, the fertilizer fraction of the total phosphorus absorbed by the plants decreased as the plants grew older. The amounts of phosphorus absorbed from the soil and the fertilizer were different for the four crops used. Soybeans absorbed the largest amount of soil phosphorus.

Further experiments were conducted to study when the differences amongst the crops in utilizing added phosphorus became larger. It was thought desirable that rape and soybeans, the former an efficient fertilizer phosphorus feeder and the latter an efficient soil phosphorus feeder, be grown to further investigate their efficiencies to extract phosphorus from different phosphate carriers and also to study the effect of widening the band on phosphorus utilization.

Mixing of a non-radioactive phosphate carrier throughout the soil decreased the absorption of fertilizer phosphorus by the plants. Results showed that rape is not any better than soybeans in extracting the added phosphate if an alternate supply of phosphorus is present. Rape absorbed more fertilizer from a narrow band but soybeans absorbed more from a wide band. Dipotassium phosphate, monoammonium phosphate, and monocalcium phosphate monohydrate were less efficient than monopotassium phosphate in supplying phosphorus to rape. But these sources were as good or somewhat better than monopotassium phosphate in their availability to soybeans. These differences could be due to the pH of the fertilizer band and the diffusion of the fertilizer etc. Monocalcium phosphate monohydrate might have diffused into a larger area than dipotassium phosphate and thus might have behaved to some extent as a wide band and therefore soybeans absorbed more phosphorus from this carrier.

The plants behaved differently in absorbing fertilizer applied in a wide and a narrow band. This observation led to an experiment in which the fertilizer was applied by four different methods. Besides applying the fertilizer as a solution in a wide and a narrow band the fertilizer crystals were applied in a thin band which is somewhat similar to the narrow band treatment. Moreover, the fertilizer crystals were also placed in the center of the pot to provide phosphorus from a point source.

The results clearly showed that the crops absorbed different amounts of phosphorus from the fertilizer depending upon the method of application. Rape made most efficient use of the fertilizer when it was applied as a point source. But for soybeans, flax, and oats this was the least efficient method in supplying phosphorus to the plants. The higher uptake of the fertilizer by these crops when the area of fertilizer application was increased seems to be due to an increase in the number of absorption sites for the roots of the plants. It is important that proper method of fertilizer application be selected for the most efficient use of the fertilizer.

The differences amongst the crops became larger when the fertilizer crystals were applied as a point source in the centre of the pot. This method of placement was selected for another experiment. Monopotassium phosphate, dicalcium phosphate dihydrate, and dipotassium phosphate were used as the phosphate carriers.

For rape and buckwheat the "crystals centre" method was slightly better than the "crystals spread" method but was a very poor method for flax and oats. Dipotassium phosphate was more available than monopotassium phosphate to flax and oats. The higher availability of dipotassium phosphate could be due to its diffusion in a larger area around the fertilizer zone.

The amount of soil phosphorus extracted by a plant was dependent upon the availability of the added phosphate and the level of available phosphorus in the soil. The "A" values were high for plants grown on phosphorus rich soil.

The largest difference amongst the crops was obtained where dicalcium phosphate dihydrate crystals were used. All the results for buckwheat showed that its feeding efficiency is similar to that of rape. It was then thought appropriate to use a very insoluble source of phosphorus to see if they differ in phosphorus uptake from such a carrier. This led to the use of octacalcium phosphate which was applied as "crystals centre". But this also could not differentiate the abilities of rape and buckwheat to extract added phosphorus.

All these studies were conducted on calcareous soils. Another pot experiment was designed for which a non-calcareous soil was used. The methods of fertilizer application were "crystals spread" and "crystals centre".

Rape and buckwheat absorbed more phosphorus from the crystals placed in the centre of the pot than from the crystals spread uniformly as a narrow band in the calcareous soil but the opposite was found in the noncalcareous soil.

A comparison of the two soils showed that flax and the cereals absorbed more fertilizer on the noncalcareous soil than on the calcareous soil when the fertilizer was applied as "crystals centre". The difference between the efficiency of the two methods of fertilizer application in supplying phosphorus to flax and the cereals was greater on the calcareous soil than on the noncalcareous soil.

The differential phosphate feeding abilities of the plants could be due to the difference in the ability of a single root to solubilize the phosphates before absorption and also due to the difference in the ability of the root to translocate absorbed phosphates to other parts of the plant.

A single root of rape was found to be very efficient in absorbing large amounts of the fertilizer which seems to be due to its ability to solubilize and translocate phosphorus to other parts of the plant. Flax and oats do not have this characteristic. A single root of buckwheat was more efficient or less efficient than rape depending upon whether the root passed very close to the fertilizer crystals and branched or it was away from the crystals and did not branch. A distinct concentration of roots in the vicinity of the fertilizer was found with rape but not with flax and oats.

Two nutrient solution experiments were then conducted so that the problem of solubilizing the phosphates was eliminated and thus it was possible to study absorption and translocation of phosphorus. A split root technique was used in which a single root was allowed to grow in one solution in a tube and rest of the roots remained in another solution contained in the jar.

A single root of rape in the presence of other nutrients absorbed two-thirds of the phosphorus absorbed by all the other roots. The single roots of other crops, on the other hand, were much less efficient than the rest of the roots. There was no absorption of phosphorus by a single root of flax from high phosphorus concentrations in the solutions used.

The presence of other nutrients had a favourable effect on the growth of the single roots of all the crops. This effect was particularly manifested in rape. A lesser effect was shown in flax. The presence of other nutrients only slightly increased the growth of the single roots of oats and buckwheat.

In the absence of other nutrients the efficiency of a single root in absorbing and translocating phosphorus decreased as follows: buckwheat, oats, and rape. However, in the presence of other nutrients the order was as follows: rape $>$ buckwheat $>$ oats. Thus it is obvious that the presence of other nutrients is very essential for phosphorus uptake by a single root of rape. The other nutrients increased both the growth and the absorption of phosphorus by a single root of rape. Although the presence of other nutrients did not increase appreciably the growth of the single root of oats and buckwheat, it did increase the uptake of phosphorus. On the contrary, the presence of other nutrients increased the growth of the single root of flax but did not have any favourable effect on phosphate absorption. However, in a preliminary experiment it was noted that the presence of other nutrients had a favourable effect on the growth of a single root of flax and also on the absorption of phosphorus from solutions low in phosphorus concentration.

The uptake of phosphorus by a single root of the plants was found to be directly dependent on the extent of root growth. On the basis of equal weights of a single root rape was not any better than oats and buckwheat; in fact, oats and buckwheat were much more efficient than rape.

In a short-term experiment a single root of plants at three different stages was supplied with a solution containing 93 ppm of phosphorus. No other nutrients were available to the single roots. It was found that a single root of buckwheat absorbed and translocated more phosphorus than a single root of rape. The efficiency of oats was slightly less than buckwheat in this respect. A single root of flax did not absorb phosphorus from this solution. It was also found that the age of the plant has an important bearing on the absorption and translocation of phosphorus by a plant.

The results suggest some of the reasons why crops differ in their abilities to absorb added phosphorus. For example, the roots of rape branch out very profusely and since phosphate absorption is dependent on the size of the roots, rape makes very efficient use of the fertilizer. Flax does not make efficient use of the added phosphorus because the roots can not absorb phosphorus from a concentrated source.

Rape and buckwheat were almost similar in their efficiencies to extract phosphorus no matter which carrier was used. But the reason for this efficiency is not the same. Rape absorbs high amounts of the fertilizer because of a well branched root system since phosphorus uptake is directly proportional to the size of the root. Buckwheat is efficient because on the basis of equal weights of the roots it can absorb much more phosphorus than can rape.

It is advisable that further studies should be carried out with these plants to investigate the effect of varying phosphate concentrations and environmental conditions on phosphorus uptake so that definite conclusions can be drawn.

This appears to be essential for a better understanding of the phosphate feeding abilities of different crops.

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