

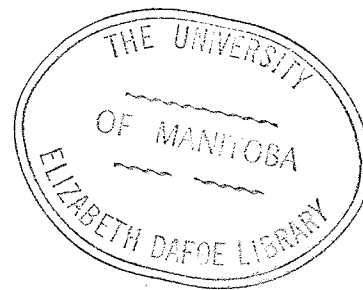
THE PHOSPHORUS FEEDING HABITS OF FLAX, CEREALS AND RAPESEED

A Thesis

Presented to

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ABSTRACT

Previous field and greenhouse experimental evidence indicated that field crops showed differential responses to band applications of fertilizer phosphorus. An investigation including field and greenhouse experiments was conducted to study the phosphorus feeding habits of three field crops: flax, a cereal and rapeseed.

The quantities of phosphorus taken up and the rates of phosphorus uptake during the growing season were different for the three crops. All crops were able to extract phosphorus from dilute phosphate solutions but they differed with respect to the quantities of phosphorus each was able to remove from the solutions.

Rapeseed made most efficient use, oats made less efficient use than rapeseed and flax made least efficient use of phosphorus from a fertilizer band. Rapeseed showed the greatest response, oats showed less response than rapeseed and flax showed the least response to banded fertilizer phosphorus.

Oats was shown to be the strongest soil phosphorus feeder. Flax and rapeseed have about equal soil phosphorus feeding powers.

"A" values, measures of available soil phosphorus, determined for the three crops with band applications of phosphorus fertilizer decreased in the order flax, oats, rapeseed. It was suggested that the "A" value determination may in the future be used as a method of estimating the responsiveness of crops to band applications of fertilizer phosphorus.

INTRODUCTION

Do plants vary in their ability to feed on insoluble or difficultly soluble nutrients?

In a review article written in 1930 entitled "The Feeding Power of Plants" W. Thomas (32) stated: "the evidence is overwhelming that different plants growing in media of identical composition not only exhibit differences in composition that can only be interpreted to indicate marked differences in type of absorption, but that they also exhibit differences in what has been frequently designated in the literature by the term 'feeding power' or ability to utilize insoluble soil constituents to different degrees which are characteristic of the species".

The question of differential plant feeding power particularly with respect to soil phosphorus and a wide range of phosphate fertilizers has commanded the attention of a large number of workers in the fields of plant physiology and soil science. The use of P32 tracer has in recent years enabled workers to gain a much wider knowledge of the phosphorus feeding habits of plants than was previously possible.

Workers at the University of Manitoba became interested in the phosphorus feeding habits of different plants during the summer of 1961 when it was observed that of four field crops; flax, rapeseed, oats and corn grown in a plot in the Portage la Prairie, Manitoba, area, only rapeseed responded to a relatively small application of

phosphate fertilizer applied alone and in combination with nitrogen. Since the crops were grown under similar conditions of soil and climate the results obtained were interpreted to imply a real difference between the phosphorus feeding habits of rapeseed and the other three crops.

To study the phosphorus feeding habits of some field crops Webber (33) conducted a greenhouse experiment in which he grew three crops on three soils (two of them Portage soils) fertilized with phosphate fertilizer containing tracer P32. He grew rapeseed, oats and flax. Rapeseed was grown because of the interesting field data previously obtained. Flax was grown because to that date flax grown in Manitoba had shown only very variable responses to phosphate fertilizer. Oats was grown because some data had previously been collected concerning the phosphorus feeding habits of oats (8, 9, 16, 22). It was felt that the data obtained for oats might serve as a standard to which the flax and rapeseed data could be compared.

On the basis of experimental data Webber (33) concluded that when grown on soils having low amounts of plant available phosphorus rapeseed makes more efficient use of fertilizer phosphorus than does oats. Flax makes very inefficient use of fertilizer phosphorus. "A" values determined for the Portage soils decreased in the order flax, oats, rapeseed. These data imply that the amounts of soil phosphorus available for use by the growing crops is largest for flax, smaller for oats and least for rapeseed.

The data obtained from the greenhouse experiment supported the

belief that crops differ in their ability to feed on insoluble or relatively unavailable forms of phosphorus in the soil. Since flax, oats and rapeseed are economically important crops in Manitoba it was felt that further knowledge concerning their abilities to extract soil phosphorus and to use fertilizer phosphorus would be of value in making fertilizer recommendations for these crops.

LITERATURE REVIEW

That species differ in their ability to extract phosphorus from difficultly soluble phosphates is well known. Although several theories have been advanced to explain inter-specific differences in the phosphorus feeding powers of plants, the question; "are inter-specific differences in the phosphorus feeding power of plants great enough to be of significance to agriculture?" has remained largely unanswered.

As early as 1898 Merrill (21) reported that the influence of rock phosphate on growth of plants varied with the species.

Ballard and Dean (1) reported that the rate and total uptake of radioactive phosphorus added to soils vary with the soil and the species of plant grown.

Russell, Russell and Marais (28) stated that inter-specific differences in the extent to which different species absorb phosphate are well known, but there is little evidence to show whether they are due to some forms of phosphate in the soil being accessible to some species only or whether species differ merely in the rates at which they absorb from a common source.

Russell (27) in his book "Soil Conditions and Plant Growth" stated that the roots of some plants can almost certainly increase the rate at which insoluble phosphate is brought into solution either because they excrete calcium-complexing acids or because they have bacteria associated in their rhizospheres which can bring phosphate

into solution. He cites examples. Oats growing with Lupins or white clover can take up more phosphorus from an insoluble phosphate than if growing alone; or a cereal following buckwheat manured with an insoluble phosphate will take up more phosphorus than if the preceding crop were another cereal.

Gerretsen (11) grew oats, mustard, rapeseed and sunflowers under sterile and infected conditions to study the influence of microorganisms on phosphate uptake by these plants. The plants were grown in sand to which insoluble or difficultly soluble phosphates had been added. It was concluded that microorganisms make available to plants a certain amount of otherwise unavailable phosphorus. In a number of sterile cultures, however, the amount of phosphorus assimilated by plants from such substances as tri-calcium phosphate and bone meal, though much smaller than in the infected cultures, was quite considerable. He thought these data definitely proved that in the absence of microorganisms plant roots may take an active part in dissolving difficultly soluble phosphates.

Dean and Fried (3) reported that, in general, the most efficient users of rock phosphate were lupins, buckwheat, sweet clover, mustard, swiss chard, vetch, and to a lesser extent, alfalfa, peas, rapeseed and cabbage. Cotton, cowpeas, bur, clover, rice, oats, barley, millet, rye and wheat are considered to be very poor users of rock phosphate.

Fried (10) grew seven crops; barley, buckwheat, beets, alfalfa, oats, sweet clover and rye grass on three soils to study the utilization

of phosphorus added as monocalcium phosphate. Results indicated that the availabilities of monocalcium phosphate added to the soil and soil phosphate were similar for the species tested with the exception of beets in one test. It was suggested that a rapid reaction between monocalcium phosphate and soil to form phosphorus complexes similar to those in the soil may have been responsible for the observed similarity among species.

In a second experiment buckwheat, alfalfa, crotonaria, oats, beets and a perennial ryegrass were grown on a soil to which had been added radioactive monocalcium phosphate at a rate of 100 lbs. of P_{205} per acre and inactive Florida pebble rock phosphate at a rate of one ton per acre. Since, in the previous experiment none of the species except beets in one trial showed significant differences in their abilities to feed on monocalcium phosphate relative to soil phosphate, the differences between species in the percentage uptake of phosphorus from the soil phosphate and rock phosphate observed in the second experiment were due to the presence of rock phosphate. Results indicated that the phosphorus in rock phosphate was most available to buckwheat and was more available to legumes, alfalfa, crotonaria and ladino clover than to the grasses; orchard grass, perennial ryegrass, bromegrass, millet and oats. Fried concluded from his work that differences between species in their capacity to absorb phosphorus from basic calcium phosphates not only reflect differences in root size and extensiveness, but also differences in specific species-source interactions.

Jenkins (15) studied phosphorus utilization by grasses and clovers from two soils, one of them being phosphate deficient. At first harvest the phosphate removal from the deficient soil was significantly greater by clover than by ryegrass. At the second harvest the amount of phosphorus in clover was greater than that in ryegrass for both soils. It was concluded that clover is a stronger phosphorus feeder than is ryegrass since it was able to obtain more phosphorus when the supply of soil phosphorus was limited.

Karpinskii, Zamyatina and Glazunova (16) grew crops of buckwheat and oats to study plant utilization of phosphorus from soddy podzolic soils differing in degree of fertility and texture. Buckwheat absorbed more soil phosphate than did oats.

Russell, Russell and Marais (28) grew barley, rye and cabbage and measured the labile soil phosphate for several soils by the Larsen method (19). For some soils, the "L" values determined with rye and cabbage were higher than those determined with barley. It was suggested that rye and cabbage have a greater ability than has barley to lower the free energy of phosphate in the external medium (i.e. the soil solution).

Webber (33) grew flax, rapeseed and oats and measured the labile soil phosphate for three soils by the phosphorus fertilizer band "A" value method. It was observed that when grown on soils having a relatively low level of sodium bicarbonate-extractable phosphorus the "A" values for the three crops decreased in the order flax, oats, rapeseed. Rapeseed made more efficient use of fertilizer phosphorus

than did oats. Flax made very inefficient use of fertilizer phosphorus.

It was suggested that the differences between "A" values for the crops which resulted from differences in the ratio of fertilizer phosphorus to soil phosphorus in the plant material may have been due to one or more of several factors:

1. Flax, oats and rapeseed differ in their ability to utilize relatively unavailable soil phosphates.

2. Flax, oats and rapeseed differ in their manner of phosphate utilization. Flax, it was postulated, may require small amounts of phosphorus throughout the duration of its growth. Rapeseed and oats, on the other hand, may require relatively large amounts of phosphorus at particular stage(s) of growth. A soil having a relatively low level of available phosphorus may be able to supply the phosphorus required by flax but not that required at certain stages by oats or rapeseed. Thus, even if all crops prefer to use soil phosphorus, oats and rapeseed find it necessary to utilize fertilizer phosphorus, whereas flax does not.

3. The pH of the fertilizer band may be more conducive to the development of oat and rapeseed roots than to the development of flax roots in the band area.

Nye and Foster (24) used radioactive phosphorus to compare the abilities of crops to use less readily available soil phosphates. The differences in phosphorus feeding power determined were small and were considered agriculturally insignificant. Marked differences which occurred in the total phosphorus uptake by the crops were attributed

to differences in the extensiveness of root absorbing surfaces and to unequal rates of phosphorus uptake at a given level of phosphate activity in the root environment.

In another study Nye and Foster (25) grew members of the families Leguminosae, Cruciferae, Graminae and Solonaceae to determine "L" values (19) measures of labile soil phosphorus, for three soils low in plant available phosphorus. When plants having small seeds were grown it was shown that the "L" values determined were essentially the same for all plant species used or that only agriculturally insignificant differences could be found in the proportion of soil phosphorus to added tracer P32 taken up by the plants.

Smith (30) subjected four inbred lines of corn and six of their crosses to deficiencies of phosphorus and nitrogen. Varying phosphate efficiency observed between the lines and crosses was explained on the basis of inherited differences in root type. A high ratio of secondary to primary roots was found for the phosphate efficient lines and a low ratio for the phosphate inefficient lines.

Lyness (18) reported that three varieties of Reids Yellow Dent corn, when compared with one another, showed capacities for absorbing phosphorus from cultures of similar concentration in the ratio 3:5:7. A high correlation between phosphate response and the number and character of secondary roots suggests that, as was postulated by Smith, differences in phosphate efficiency between varieties of corn may be due to differences in the development of the secondary root system.

P32 tracer has enabled workers in soil science to study the efficiency with which field crops utilize applied fertilizer phosphorus. Agriculturally significant differences in efficiency of fertilizer use between species and between varieties of some species have been elucidated.

Mitchell, Dion, Kristjanson and Spinks (22) used P32 tracer to study the uptake of soil and fertilizer phosphorus by varieties of wheat, oats and barley grown on a moderately and a highly responsive soil. Barley showed a significantly greater ability to utilize fertilizer phosphorus than did wheat, but there was no significant difference between wheat and oats or oats and barley. Varietal differences in response to fertilizer phosphate were obtained only for barley.

Skupinska (29) reported no significant differences in the capacities of four flax varieties to use fertilizer phosphorus.

Krantz, Nelson, Welch and Hall (17) compared the utilization of fertilizer phosphorus by corn, potatoes and soybeans grown on two Bladen soils, one having a high and the other a low level of available soil phosphate. Corn and cotton were similarly compared on the Norfolk series soil. Comparison of potatoes, corn and soybeans showed that potatoes absorbed the most fertilizer phosphorus and soybeans the least. Corn absorbed the most total phosphorus and potatoes the least. Although the percentage of phosphorus in the plant material derived from the fertilizer was highest for corn at first sampling, the percentages for both corn and soybeans decreased sharply during the growing season. Potatoes absorbed a relatively high proportion of

fertilizer phosphorus throughout the growing season.

Comparison of corn and cotton showed that corn absorbed the most fertilizer phosphorus and also the greatest total amount of phosphorus.

Frey, Robertson, Cook and Down (9) reported that barley varieties show differential responses to fertilizers of varying analyses. They suggest that on the basis of past literature, in general, crops in which one variety has a small area of adaptation (e.g. corn) tend to show a significant variety by fertility interaction, whereas those crops in which any one variety has a large area of adaptation (e.g. oats) do not show significant variety by fertility level interactions.

METHODS AND MATERIALS

Determination of nitrate nitrogen in the soil profile

In the field experiments, soil samples were taken from the 0-40 treatment soils of each crop in the five replicates at each harvest date. Five samples, one of each of the 0"-6", 6"-12", 12"-24", 24"-36" and 36"-48" depths were taken at each site. The colorimetric phenoldisulphonic acid method as modified by Harper (12) was employed to determine the quantity of nitrate nitrogen in parts per million in each soil sample. The quantity of nitrate nitrogen in lbs. per acre to a depth of four feet at each sample site was calculated using soil bulk density measurements.

Determination of total nitrogen in plant material

The Kjeldahl procedure as modified by Winkler (34) was employed to determine the nitrogen content of plant material samples.

Determination of total phosphorus in plant material

Ashing Procedure. Plant material samples for total phosphorus determinations and for radioactive counting by the solution method were wet ashed using a modification of the procedure outlined by Jackson (14). The suggested predigestion with concentrated HNO_3 before addition of the ternary acid mixture was omitted.

Total phosphorus determination. The colorimetric method outlined by Barton (2) was used to determine the quantity of phosphorus in the ash solutions.

Preparation of radioactive fertilizer solutions

Carrier free P32 for use as a tracer in greenhouse experiments was obtained in one millicurie quantities as a NaH_2PO_4 solution from Charles E. Frosst and Co., Montreal. The quantity of solution received was diluted to one litre to produce a solution originally containing 1 uc of P32 per 1 ml. of solution.

Greenhouse experiment I. One litre of a radioactive fertilizer solution containing 720 uc of P32 and 1.8 gm. of P31 was prepared. 10 ml. of the solution added to 1800 gm. of air dry soil delivered 10 ppm of P31 and 7.2 uc of P32 to the soil.

Greenhouse experiment II. One litre of a radioactive fertilizer solution containing 900 uc of P32 and 1.8 gm. of P31 was prepared. 10 ml. of the solution added to 1800 gm. of air dry soil delivered 10 ppm of P31 and 9.0 uc of P32 to the soil.

The radioactive fertilizer solutions remaining after all treatments in each experiment had been prepared were stored in polyethylene containers to be used as standards against which the counts of the respective plant materials might be compared.

Method of counting radioactive P32

The radioactive ash solutions of plant materials produced in experiments I and II and in the nutrient solution experiment were counted using a type D.M. 6 solution tube connected to a Nuclear Chicago Model 161 A Basic Binary scalar. By comparison with the appropriate standard, the activity (c.p.m.) of the test samples was

converted to microcuries of P32 taken up or to per cent utilization of added fertilizer phosphorus.

FIELD EXPERIMENTS

Webber (33) suggested that the observed differences between the phosphorus feeding habits of flax, oats and rapeseed might be due to:

1. Differences between the crops with respect to their rates of phosphorus utilization at certain stages of growth.
2. Differences between the crops with respect to the extents of their root systems.
3. Differences between the crops with respect to the total quantities of phosphorus required for growth to maturity.
4. Differences between crops with respect to their abilities to utilise phosphorus from a phosphate fertilizer band.

With the above-mentioned ideas in mind a field experiment of approximately one-half acre area in which flax, wheat and rapeseed were to be grown was designed. The experiment was located on a fallow and on a stubble site and a study of the three crops was conducted to determine and compare:

1. The rates of phosphorus and nitrogen utilization throughout the growing season.
2. The total amounts of phosphorus and nitrogen required for growth and seed production.
3. The rates of vegetative growth and development.
4. The responses to nitrogen and phosphorus fertilizer applied alone and in combination.
5. The total yields of plant material and seed.
6. The extent of root development at several stages of growth.

The field plot design was a split plot randomized block experiment containing five replicates. Each replicate contained six harvests of four fertilizer treatments for three crops. The fertilizer treatments of each crop were randomized but were planted side by side to form three blocks of the three crops in each replicate. The blocks within the replicate were split in half so that two harvests of plant material might be obtained from each. The harvests were randomized within each replicate.

Each treatment consisted of six, 30-foot rows. Two ten-foot sections of the two center rows of each treatment in all replicates were harvested during the summer. The four outside rows acted as guard rows. The four fertilizer treatments were:

1. Check treatment (no fertilizer added) 0-0.
2. 60 lbs. per acre of nitrogen broadcast in the form ammonium nitrate (60-0).
3. 40 lbs. per acre of P_2O_5 in the form of monocalcium phosphate drilled in with the seed (0-40).
4. 60 lbs. per acre of nitrogen broadcast and 40 lbs. per acre of P_2O_5 drilled in with the seed.

The two field experiments were located approximately four miles apart in the Portage area. The fallow site, a Portage loam soil (4), was situated on the McAllister farm; the stubble site, a Portage fine sandy loam (4) was situated on the Yuill farm. A characterization of the soils is given in Table I.

Seeding was done with a self-propelled, six-row seeder. Enough

TABLE I
SOME CHARACTERISTICS OF THE FALLOW AND STUBBLE PLOT SOILS

	Fallow soil	Stubble soil
pH	7.85	7.65
Conductivity of satn. extract (mmhos per cm.)	.84	.42
Texture	L.	F.S.L.
% organic carbon	4.90	4.68
% organic matter	8.45	8.06
% inorganic carbonate	1.71	.26
CaCO ₃ equivalent (%)	2.86	.44
NaHCO ₃ -extractable phosphorus (ppm)	9.80	6.17
Exchangeable potassium (ppm)	332.0	502.0

seed or seed and phosphate fertilizer was placed uniformly along "V" belts to plant a 30 foot row, i.e. one treatment. When the seeder moved forward the seed or seed and fertilizer mixture was evenly metered out along the length of the row. Nitrogen fertilizer was broadcast by hand on the appropriate treatments after seeding was completed.

The fallow and stubble plots were seeded on June 4 and 5 respectively. Selkirk wheat was planted at a rate of two bushels per acre, Golden rapeseed at a rate of six lbs. per acre and Marine flax at a rate of 40 lbs. per acre.

Harvests to determine the yields in pounds per acre of oven dry plant material and utilization in pounds per acre of nitrogen and phosphorus were taken on five different dates during the growing season. Concurrent with each harvest date soil samples to a depth of four feet were taken from the 0-40 treatment soil of each crop for per cent moisture determinations and nitrate nitrogen analyses. The first four harvests were taken 21, 36, 49 and 62 days after the seeding date. The fifth and final harvest was taken at maturity and its date varied for the different crops. A harvest consisted of cutting at ground level and collecting all the plant material from two ten foot lengths of the center two rows for each treatment in one block of each of the five replicates in the plot. The plant material from each treatment was bagged, dried in an oven at 90° C. and weighed. The yield of oven dry plant material in pounds per acre was calculated for all treatments of the crops at each harvest and, in addition, the

yield of seed was determined for the final harvest. Subsequent to weighing, the plant material and the seed samples were ground in a Wiley mill so that representative samples might be obtained for total phosphorus and total nitrogen analyses. The amounts of nitrogen and phosphorus in lbs. per acre in the plant material were calculated for each treatment of the three crops at the five harvest dates.

On July 24, two days prior to the third harvest, a moderately severe hail and rainstorm passed over the fallow site. The wheat and flax were blown down and the tender rapeseed shoots were broken over about one foot above the ground. As a result, the data of maturity for all crops was delayed. The wheat lodged, severely reducing the seed yield. The broken over rapeseed stocks grew up again but maturity was delayed so much that it was necessary to harvest that crop somewhat before all the seed produced had matured. Although the flax plants straightened and grew, with little noticeable damage, it is felt that the storm appreciably reduced the seed yield of that crop.

It was hoped that the extent of root development by flax, rapeseed and wheat might be compared at several stages of growth by determining to what depth NO_3 -nitrogen and moisture had been removed from the soil. Such a comparison was made impossible by the frequent rains which fell on the plots throughout the summer, resulting in excessive movement of NO_3 -nitrogen in the soil profile by leaching and practically no depletion of soil moisture at any depth.

Results and Discussion

Nitrate nitrogen in the soil profile

The contents of nitrate nitrogen in lbs. per acre in the soil profile to a depth of four feet, before seeding and at each harvest thereafter for the fallow and stubble plots are listed in Tables II and III respectively.

Fallow plot. The average quantity of nitrate nitrogen in the fallow soil prior to seeding was 345 lbs. per acre, a surprisingly large amount. Soper (31) states that fallow sites sampled in the early spring in Manitoba contain on the average 100 lbs. per acre of nitrate nitrogen. The soil at the fallow plot site, from the viewpoint of available nitrogen status, was much more fertile than the average Manitoba soil.

Soil samples taken before seeding and subsequent samples taken during the summer clearly indicated that the quantities of nitrate nitrogen in the soil profile varied widely within a small area of soil. The wide variation was probably not a critical factor in crop growth since all sites sampled in the spring contained more than 100 lbs. per acre of nitrate nitrogen. Huang (13) stated that if the amount of nitrate nitrogen accumulated in the four foot soil profile exceeded 80 lbs. per acre in the early spring, nitrogen fertilization is not considered necessary for cereal crops.

In general, there was a decrease in the nitrate nitrogen content of the fallow soil with continued plant growth throughout

TABLE II

LBS. PER ACRE OF NITRATE NITROGEN IN THE FALLOW SOIL TO FOUR FEET

Before seeding	Crop	Replicate	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V
N. W. corner of plot	Wheat	I	411.4	190.6	125.5	434.4	232.3
S. W. corner of plot		II	254.0	179.5	345.6	210.0	100.4
N. E. corner of plot		III	183.7	456.8	103.4	331.4	78.6
S. E. corner of plot		IV	250.1	65.2	66.1	37.1	45.9
W. center of plot		V	431.9		96.4	145.7	43.6
E. center of plot		Average		306.2	223.0	147.4	231.7
Average			344.8				
	Rapeseed	I	306.4	201.7	89.8	204.9	104.5
		II	543.9	247.6	49.3	169.2	24.8
		III	356.2		89.8	23.7	116.8
		IV	149.3	184.5	131.6	123.4	121.8
		V	268.0		27.8	215.3	14.8
		Average		338.9	211.2	77.6	147.3
	Flax	I	291.8	320.6	69.9	343.8	139.2
		II	333.4	231.5	96.5	275.1	27.6
		III	147.6	121.7	13.0	60.8	263.4
		IV	607.3	178.1	159.6	341.0	61.0
		V	257.5		302.5	172.8	176.7
		Average		345.0	212.9	128.3	238.7

the growing season. The increase observed at harvest IV was considered to be a result of the hailstorm. During the two-week period following the storm the crops recuperated and it would appear that they used decreased amounts of nitrogen. At the same time, conditions of moisture and temperature were ideal for nitrification and large amounts of nitrate nitrogen were elaborated.

The nitrate nitrogen data suggested that rapeseed may require more nitrogen for its growth than does flax or wheat. On the average the nitrate nitrogen contents of soils on which rapeseed grew were lower than those on which wheat and flax were grown.

Stubble plot. The average quantity of nitrate nitrogen in the stubble soil prior to seeding was 102.5 lbs. per acre. Similar to the fallow soil, the stubble soil showed a wide variation in nitrogen content within a small area. Particularly large variations are noted in the results obtained from replicate II.

The average values show a general decrease in the nitrate nitrogen content of the soil with continued crop growth. The stubble soil data, similar to that for the fallow soil, suggested that rapeseed may require more nitrogen for its growth than does wheat or flax.

Yields of plant material

The total yields of plant material in lbs. per acre of oven dry weight for each crop at each harvest and the yields of seed in lbs. or bus. per acre for the fallow and stubble soils are listed in Tables IV and V respectively. Graphs showing a comparison of rates of

TABLE III

LBS. PER ACRE OF NITRATE NITROGEN IN THE STUBBLE SOIL TO FOUR FEET

Before seeding	Crop	Replicate	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V
N. W. corner of plot	78.6	Wheat	I	106.2	139.7	41.2	54.6
S. W. corner of plot	76.9		II	110.9	105.9	187.4	157.4
N. E. corner of plot	158.6		III	138.8	110.6	4.3	63.3
S. E. corner of plot	58.2		IV	23.6	89.7	1.6	2.4
South center of plot	59.8		V	24.7	2.8	44.6	1.9
North center of plot	183.1		Average	80.8	109.7	75.8	55.9
Average	102.5						
		Rapeseed	I	96.2	110.0	3.4	123.9
			II	64.7	198.6	336.2	64.0
			III	183.1	86.7	24.9	23.9
			IV	33.1	3.3	.7	4.8
			V	50.4	.3	6.9	8.4
			Average	85.5	79.8	74.4	45.0
		Flax	I	122.5	215.8	36.6	77.0
			II	194.3	151.3	315.8	170.2
			III	247.1	50.4	16.4	87.1
			IV	41.6	52.9	10.5	4.5
			V	32.0	4.2	30.9	4.6
			Average	127.5	94.9	82.0	68.7

growth for the crops and the total quantities of plant material produced by each crop grown on the fallow and stubble soils are shown in Figures 1 and 2 respectively.

Fallow plot. The fallow plot yield data indicate that when the supply of required nutrients is plentiful rapeseed has the capacity to produce much larger quantities of plant material than has wheat or flax. Rapeseed produced slightly more than five tons per acre of oven dry plant material as compared to three tons per acre of wheat plant material and approximately two and one-half tons per acre of flax plant material.

The growth patterns for the three crops exhibit well defined differences. Wheat grew more quickly early in the season than did rapeseed or flax probably because wheat seed is much larger than is rapeseed or flax and contains a greater supply of nutrients, which in turn produce a bigger, more active seedling. Wheat grew rapidly during the 21-62 day period, however, at approximately 60-65 days vegetative growth stopped and there was little increase in the weight of plant matter produced thereafter until the final harvest. Rapeseed initially grew more slowly than did wheat, however, during the 21-65 day period its growth rate approximately equalled that for wheat. Beyond 65 days wheat stopped growing and rapeseed grew at a somewhat reduced rate until maturity. The amount of plant material produced by rapeseed was smaller than that produced by wheat until 70 days after seeding. The final yield of rapeseed plant material was one and two-thirds times that of wheat. Although flax initially grew even more slowly

TABLE IV

THE AVERAGE YIELDS OF PLANT MATERIAL IN LBS. PER ACRE AND THE YIELDS OF SEED GROWN ON THE FALLOW SOIL

Crop	Treatment	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V	Seed
Wheat	0-0	278.2	1896.9	3909.3	5530.6	5925.6	18.6 bus/acre
	0-40	329.2	1761.2	4090.3	5793.9	6147.8	18.6
	60-0	353.9	1851.8	4098.5	5835.1	6213.7	20.1
	60-40	376.9	1909.4	4329.0	6123.1	6147.8	18.9
Rapeseed	0-0	76.5	1061.7	2032.8	3876.3	7835.0	1012.3 #/acre
	0-40	85.6	979.4	2921.7	5086.1	10764.8	1860.0
	60-0	91.4	1127.5	3275.5	4674.6	10090.0	1753.0
	60-40	89.7	1415.6	3185.0	5143.8	10114.7	1703.6
Flax	0-0	85.6	559.6	1687.2	3456.6	4172.6	15.7 bus/acre
	0-40	82.3	567.9	1761.2	3193.2	3555.4	13.8
	60-0	106.2	658.4	1670.7	3341.4	4460.7	18.2
	60-40	74.1	592.6	1670.7	3135.6	4460.7	13.4

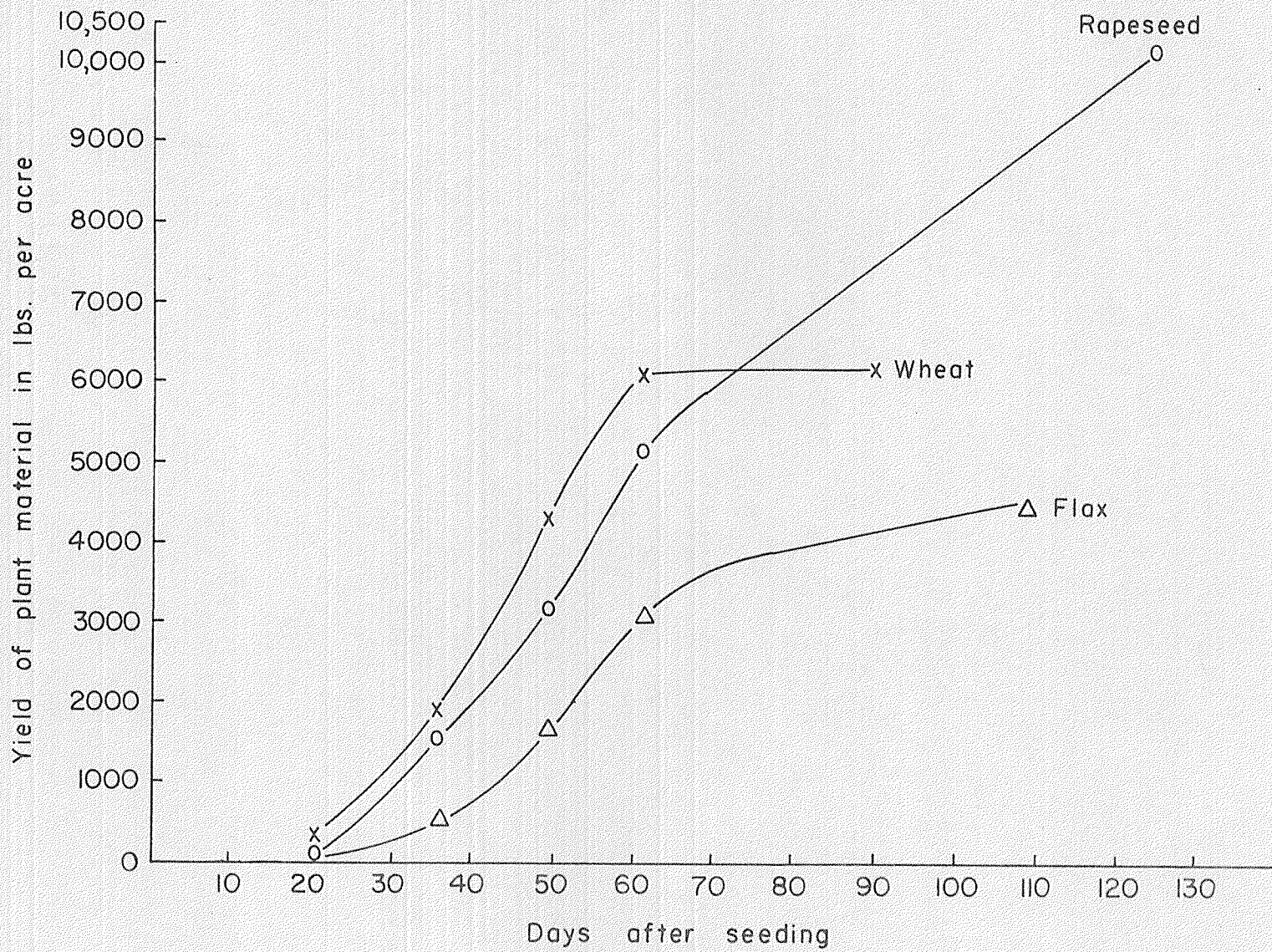


Figure 1. Growth curves for 60-40 treatment flax, wheat and rapeseed grown on fallow soil.

than did rapeseed its growth rate approximately equalled that for wheat and rapeseed during the 30-60 day period. Beyond 60 days flax grew at a greatly reduced rate until maturity. The final yield of flax plant material was somewhat less than that of wheat and about one-half that of rapeseed.

The flax and wheat seed yields were low due to lodging in the wheat and hail damage to both crops. The yield of rapeseed was good but was not as large as it would have been if maturity had not been delayed.

Rapeseed showed a greater response to phosphate fertilizer applied alone than did wheat. The 0-40 treatment rapeseed plant material and seed yields at harvest V were respectively 38 per cent and 84 per cent greater than the corresponding check yields. The 0-40 treatment plant material yield of wheat at the same harvest was 4 per cent greater than the corresponding check yield. The yield of wheat seed was neither increased or decreased by the application of phosphate fertilizer. The band application of 40 lbs. per acre of P_2O_5 with the seed reduced the germination of flax resulting in the observed decreases in the yields of plant material and seed for the 0-40 treatment as compared to the 0-0 treatment.

All crops responded to the broadcast application of nitrogen applied alone and in combination with phosphorus, although the response shown by wheat was small. The response to nitrogen was rather surprising since on the basis of nitrate nitrogen data it was concluded that the fallow soil contained more than enough nitrogen to grow the

crops to maturity. The most probable explanation for the crop responses to nitrogen is that because the added nitrogen was located in the surface soil, it was readily available to the relatively small root systems of the seedling plants and was rapidly consumed early in the growing season. As the plants grew their root systems elongated and thickened enabling them to use the native soil nitrogen located at greater depths in the soil profile. In effect, it is felt that the application of nitrogen fertilizer resulted in more rapid initial plant growth than was the case for the unfertilized plants.

It is interesting to note that wheat and rapeseed grown on the fallow soil responded approximately equally well to nitrogen or phosphorus supplied alone as to nitrogen and phosphorus applied in combination.

Stubble plot. The harvest V total yields of plant material produced on the stubble soil were approximately one-half the corresponding yields produced on the fallow soil. The data show that, as was the case for the fallow soil, the total yield of oven dry rapeseed plant material was larger than that for wheat and flax. The total yield of rapeseed plant material was approximately two and one-half tons per acre as compared to two tons per acre of wheat plant matter and one and one-quarter tons per acre of flax plant matter.

The growth patterns for flax, wheat and rapeseed grown on the stubble soil were similar to those for the corresponding crops

TABLE V

THE AVERAGE YIELDS OF PLANT MATERIAL IN LBS. PER ACRE AND THE YIELDS OF SEED GROWN ON THE STUBBLE SOIL

Crop	Treatment	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V	Seed
Wheat	0-0	176.1	839.5	2148.0	3102.7	3267.3	14.4 bus/acre
	0-40	181.1	913.5	2551.3	3827.0	3193.2	14.8
	60-0	209.0	1020.5	2353.8	3086.3	3382.5	15.1
	60-40	245.3	1201.6	3012.7	4106.8	3950.4	18.0
Rapeseed	0-0	42.0	535.0	1604.9	2403.2	3629.4	707.8 #/acre
	0-40	44.4	609.0	1917.6	3292.0	4082.1	864.2
	60-0	56.0	609.0	1662.5	2757.1	5176.7	1111.1
	60-40	51.9	666.6	2847.5	3999.8	5259.0	1316.8
Flax	0-0	82.3	658.4	1753.0	2444.3	2452.5	10.5 bus/acre
	0-40	58.4	485.6	1547.2	2329.1	2304.4	9.8
	60-0	84.8	707.8	1901.1	2872.3	2847.6	11.6
	60-40	45.3	641.9	1851.8	2345.6	2501.9	10.5

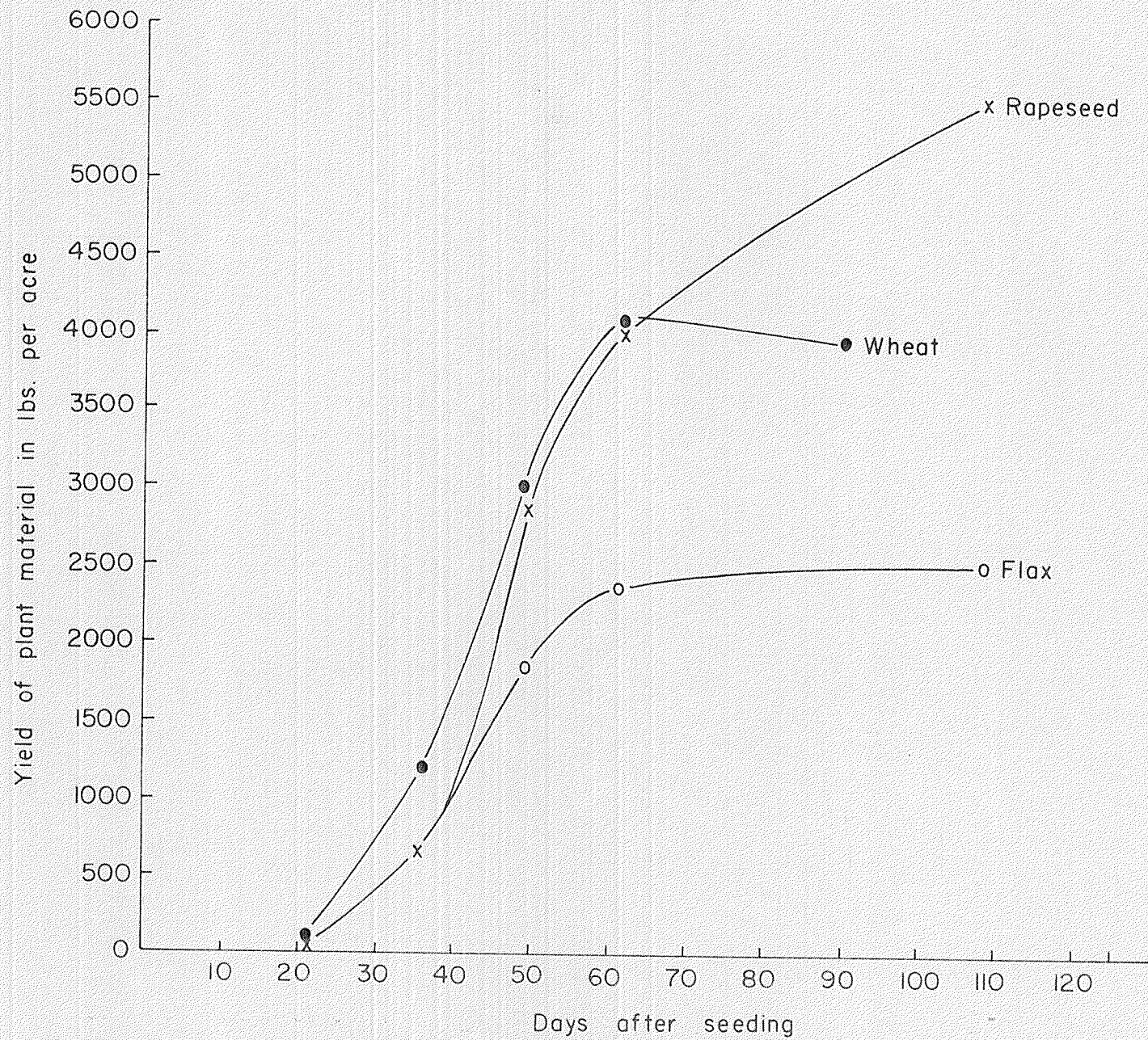


Figure 2. Growth curves for 60-40 treatment flax, wheat and rapeseed grown on stubble soil.

grown on the fallow soil. The total plant material yields of wheat were larger than those of rapeseed for each harvest up to and including harvest IV. The total yield of rapeseed plant material at harvest V was just less than one and one-half times that of wheat. The growth rate of rapeseed was somewhat less than that of wheat until harvest II. During the 36-62 day period the rate of growth of rapeseed approximately equalled that for wheat. Beyond 60-65 days wheat stopped growing. Rapeseed continued to grow at a somewhat reduced rate. The yields of flax and rapeseed plant materials were equal until about 40 days after seeding. Beyond 40 days, the rate of growth of flax decreased relative to that for rapeseed. Similar to wheat, flax nearly completed its vegetative growth by 62 days after seeding. The total plant material yield of flax was greater than one-half that for wheat and less than one-half that for rapeseed.

The yields of plant material and seed indicate that wheat grown on the stubble soil showed a much larger response to the application of nitrogen and phosphorus fertilizers in combination (60-40 treatment) than to either nitrogen fertilizer (60-0 treatment) or phosphorus fertilizer (0-40 treatment) applied alone. The yields of flax plant material and seed were increased by the nitrogen fertilizer application but were decreased slightly by the phosphorus fertilizer application due to germination damage. Nitrogen and phosphorus fertilizers applied in combination produced only a slight increase in the yield of flax plant material and no increase in the yield of flax seed over the corresponding check yield.

The graphs in Figure 3 show how the applications of nitrogen and phosphorus fertilizers alone and in combination affected the yield of rapeseed plant material. The 60-40 treatment produced one and one-half times as much plant material as did the check treatment. The 0-40 treatment produced a slight increase in the plant material yield over the check treatment yield. During the 0-62 day period the rate of growth of rapeseed for the 0-40 treatment nearly equalled that for the 60-40 treatment. Beyond 62 days the 0-40 treatment growth rate decreased more quickly than did that for the 60-40 treatment indicating that the supply of nitrogen was more limited on the 0-40 than on the 60-40 treatment. The 60-0 treatment rapeseed grew at a nearly constant rate during the 21-108 day period. Its growth rate was somewhat smaller than that for the 60-40 treatment during the 21-62 day period and somewhat larger than that for the 60-40 treatment during the 62-100 day period. These data indicate that although soil phosphorus gradually became available to the plants throughout the summer the supply of phosphorus limited the rate of growth of rapeseed for the 60-0 treatment soil. In 108 days, however, the soil was able to supply rapeseed with its total phosphorus requirement and the 60-0 treatment plant material yield approximately equalled that of the 60-40 treatment.

Phosphorus fertilizer alone increased the seed yield of rapeseed only slightly. Nitrogen fertilizer alone increased the seed yield by approximately one-third. Nitrogen and phosphorus fertilizers in combination nearly doubled the seed yield of rapeseed over that of

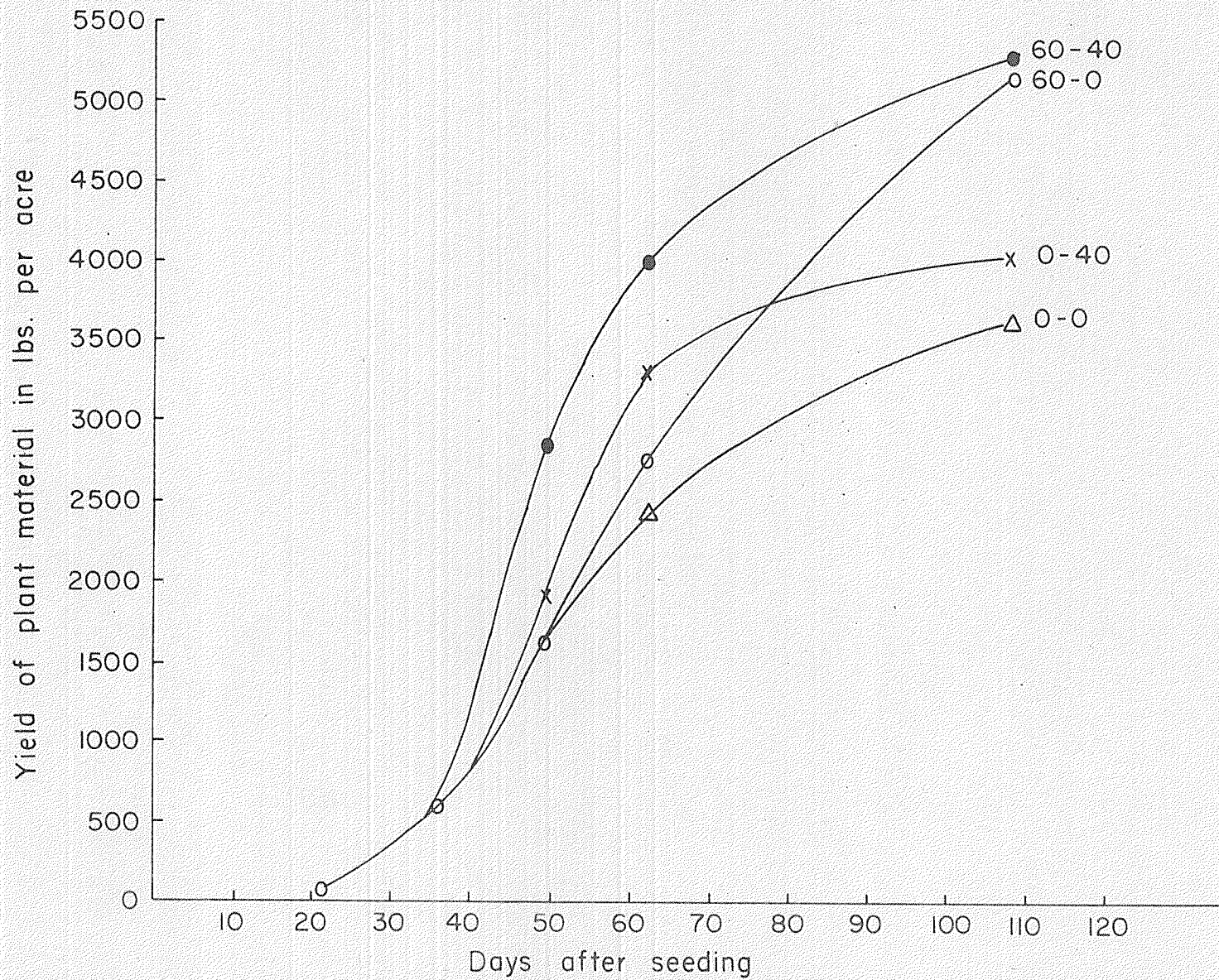


Figure 3. Growth curves for 60-40, 60-0, 0-40 and 0-0 treatment rapeseed grown on stubble soil.

the check yield.

Per cent nitrogen in the plant material

Total nitrogen analyses were conducted on all the plant material samples harvested from the fallow and stubble plots in order to determine the changes in the nitrogen contents of the plant materials as the crops grew and matured. The results of these analyses are expressed as the per cent nitrogen in the oven dry plant material and are listed in Tables VI and VII respectively.

Fallow plot. The nitrogen contents of the flax, wheat and rapeseed plant materials decreased steadily throughout the growing season. Whereas the percentages of nitrogen in the flax and wheat plant materials were approximately equal at corresponding harvest dates, those for rapeseed were somewhat larger at each date. The nitrogen contents of rapeseed and flax seed were approximately equal and were greater than that of the wheat seed. The data indicate that adding nitrogen fertilizer to the fallow soil produced little or no change in the nitrogen contents of the seed or plant materials produced by the crops.

Stubble plot. The nitrogen contents of the plant materials grown on the stubble soil were consistently lower at the corresponding harvest dates than were those of the same plant materials grown on the fallow soil. As was noted for the fallow plot data, the nitrogen contents of the plant materials grown on the stubble soil gradually decreased throughout the growing season. The nitrogen contents of

TABLE VI

THE PER CENT NITROGEN AT EACH HARVEST IN THE PLANT MATERIALS GROWN ON THE FALLOW SOIL

Crop	Treatment	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V plant material other than seed	Seed
Wheat	0-0	4.9	3.8	2.5	2.0	1.3	3.0
	0-40	5.1	3.8	2.4	2.1	1.4	3.0
	60-0	5.2	3.9	2.6	2.1	1.4	3.0
	60-40	5.2	3.9	2.5	2.1	1.4	3.0
Rapeseed	0-0	5.5	4.8	4.0	3.2	1.8	4.3
	0-40	5.8	4.8	3.9	3.3	1.4	4.3
	60-0	5.8	5.0	4.1	3.2	1.8	4.3
	60-40	5.9	5.0	4.0	3.3	1.8	4.3
Flax	0-0	4.7	4.4	2.7	2.0	1.2	4.3
	0-40	4.9	4.4	2.6	2.0	1.2	4.2
	60-0	5.0	4.4	2.8	2.0	1.2	4.3
	60-40	5.0	4.7	2.7	2.0	1.3	4.3

TABLE VII

THE PER CENT NITROGEN AT EACH HARVEST IN THE PLANT MATERIALS GROWN ON THE STUBBLE SOIL

Crop	Treatment	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V plant material other than seed	Seed
Wheat	0-0	4.3	2.5	1.7	1.3	.7	2.7
	0-40	4.5	3.1	1.8	1.4	.7	2.6
	60-0	4.9	3.5	1.8	1.5	.8	3.0
	60-40	5.2	3.7	1.9	1.5	.8	2.8
Rapeseed	0-0	5.5	3.8	2.7	2.1	.8	3.4
	0-40	5.7	4.0	2.2	2.0	.7	3.3
	60-0	5.7	5.0	3.4	2.4	.9	3.5
	60-40	5.8	5.1	2.9	2.4	.8	3.4
Flax	0-0	4.7	3.2	1.8	1.4	.8	3.7
	0-40	5.1	3.6	2.0	1.5	.9	3.8
	60-0	5.1	4.0	2.2	1.7	1.0	4.2
	60-40	5.1	4.2	2.3	1.7	1.0	4.1

flax and wheat plant materials were nearly the same at corresponding harvest dates. The nitrogen content of rapeseed plant material was somewhat larger at each date than were those of flax and wheat. Addition of nitrogen fertilizer increased the nitrogen content of flax seed more than it increased that of rapeseed and wheat.

Absolute amounts of nitrogen in the plant materials

Data for the fallow and stubble plots showing the absolute amounts of nitrogen in lbs. per acre in the plant materials at each harvest date and in the seed are listed in Tables VIII and IX respectively. Graphs showing a comparison of the nitrogen uptake at each harvest date plotted against days after seeding for the 60-40 treatments of each crop grown on the fallow and stubble soils are given in Figures 4 and 8 respectively. Graphs comparing the effects of the various fertilizer treatments on nitrogen utilization by flax, wheat and rapeseed grown on stubble soil are shown in Figures 5, 6 and 7 respectively.

Fallow plot. The environment in the fallow plot area was nearly ideal for crop growth. Temperature conditions were favorable and the supply of moisture was plentiful at all times. Nitrate nitrogen analyses of soil samples taken at each of the five harvests indicated that the supply of available nitrogen was at no time a factor limiting plant growth. This being the case it was assumed that if flax, wheat and rapeseed do differ in their capacities to utilize large quantities of nitrogen, the differences should be expressed in the fallow plot data.

The nitrogen utilization data in Table VIII indicate that rapeseed has a much greater potential to use large quantities of nitrogen than has wheat or flax. The 60-40 treatment flax, wheat and rapeseed took up 80, 125, and 230 lbs. per acre of nitrogen respectively for their growth. Rapeseed thus used two times as much nitrogen as did wheat and about three times as much nitrogen as did flax.

The three crops differ in the periods of growth during which they take up nitrogen. The graphs in Figure 4 show that wheat gained more than sufficient nitrogen from the soil during the 0-60 day growth period to satisfy its total requirement. It is interesting to note that during the 60-90 day period wheat lost nitrogen from the above ground portion of the plant. The graph for flax shows that flax took up most of the nitrogen it required for growth and seed development before 60 days after seeding and only a small portion of its nitrogen later than that date. Rapeseed took up nitrogen throughout its growth. Three-fourths of the nitrogen was taken up prior to 60 days after seeding and one-fourth was taken up between 60 and 125 days after seeding.

On the average, one-third of the nitrogen in the total wheat and rapeseed plant materials at harvest V was located in the seed. Flax seed contained approximately one-half of the nitrogen in the total plant material. In terms of seed production, then, flax made more efficient use of nitrogen taken from the soil than did wheat or rapeseed.

TABLE VIII

THE AMOUNT OF NITROGEN IN LBS. PER ACRE AT EACH HARVEST IN THE PLANT MATERIAL GROWN ON THE FALLOW SOIL

Crop	Treatment	Harvest	Harvest	Harvest	Harvest	Harvest V	Harvest V	Seed	Nitrogen in the seed as a % of the total N. in the plant material at harvest V
		I	II	III	IV	Total	plant material other than seed		
Wheat	0-0	13.7	72.3	99.3	108.4	96.6	63.4	33.2	34.4
	0-40	16.8	67.1	99.4	118.8	103.6	70.4	33.2	32.0
	60-0	18.2	72.4	105.7	123.2	105.6	69.1	36.5	34.6
	60-40	19.8	74.7	109.9	125.5	106.2	72.2	34.0	32.0
Rapeseed	0-0	4.2	50.8	80.5	122.1	164.4	120.8	43.6	26.5
	0-40	4.9	46.8	113.1	168.8	205.7	125.7	80.0	38.9
	60-0	5.3	56.0	132.7	148.2	222.4	146.7	75.7	34.0
	60-40	5.3	70.3	127.4	169.3	228.7	154.8	73.9	32.3
Flax	0-0	4.0	24.9	45.9	68.5	78.5	40.8	37.7	40.8
	0-40	4.0	24.8	45.4	63.9	66.3	33.7	32.6	49.2
	60-0	5.8	29.1	45.9	68.2	84.9	40.9	44.0	51.8
	60-40	3.7	27.9	44.9	63.3	80.5	48.6	31.9	39.6

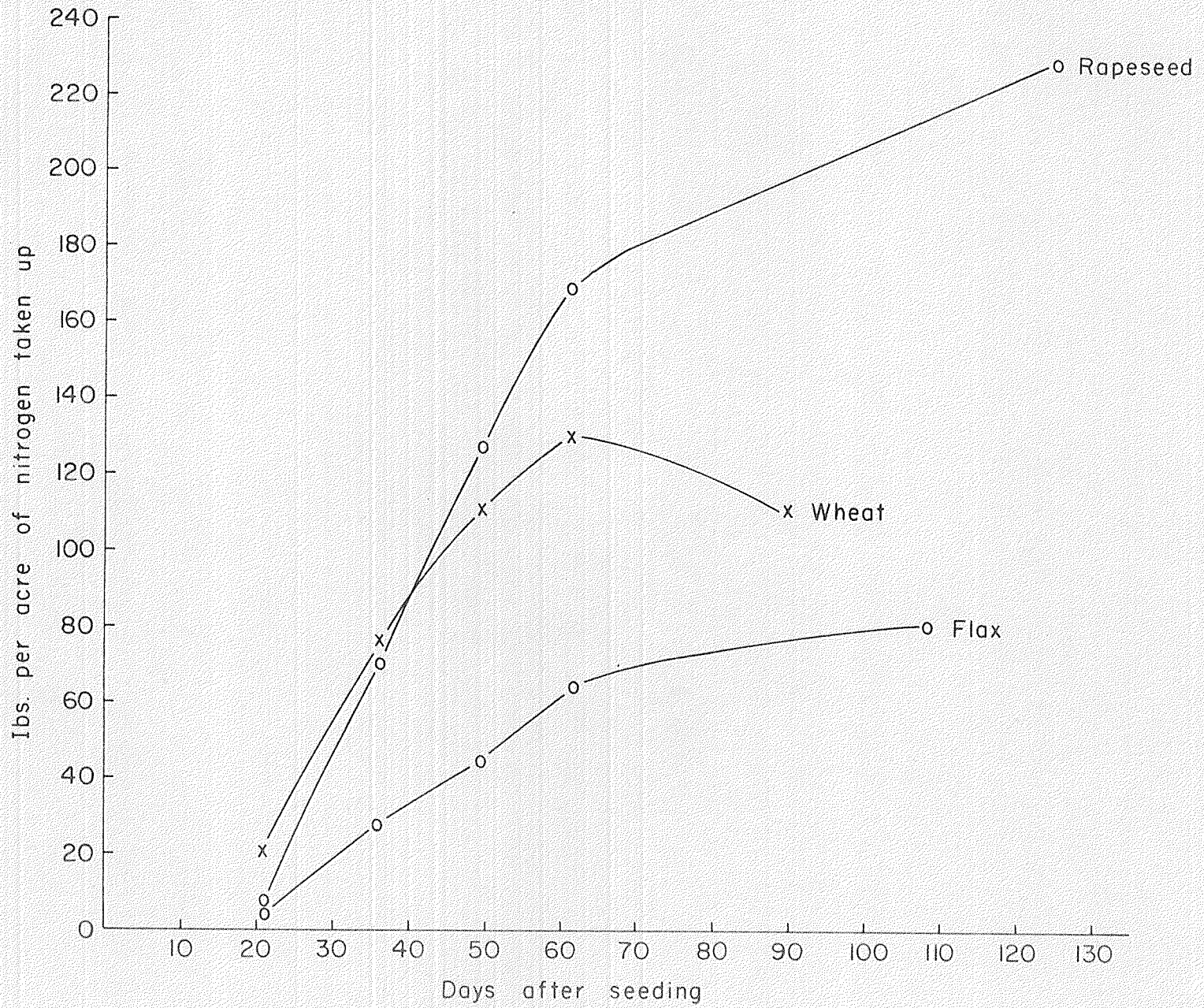


Figure 4. Nitrogen uptake for 60-40 treatment flax, wheat and rapeseed grown on fallow soil.



Stubble plot. Nitrate nitrogen analyses of soil samples taken at each of the five harvest dates during the summer indicated that probably in most areas of the plot the supply of available nitrogen was a factor limiting plant growth for at least a portion of the growing season. This being the case, large differences in nitrogen uptake were expected between crops and between the various fertilizer treatments of each crop.

The nitrogen uptake data indicate that the total quantities of nitrogen used by the three crops when grown on the fallow soil were approximately two times as large as those used by the same crops grown on the stubble soil. The 60-40 treatments of flax, wheat and rapeseed grown on the fallow soil took up 80, 125 and 230 lbs. per acre of nitrogen respectively. The corresponding values for the stubble soil were 49, 60 and 97 lbs. per acre of nitrogen. The values cited are the maximum nitrogen uptake values determined for each crop. Those given for wheat grown on the fallow soil and rapeseed and wheat grown on the stubble soil were determined at harvest IV. All other values were determined at harvest V.

The graphs in Figures 5, 6 and 7 show how adding nitrogen and phosphorus fertilizers affected nitrogen utilization by flax, wheat and rapeseed respectively. The 60-40 and 60-0 flax treatment total plant materials at harvest V contained 15 lbs. per acre more nitrogen than did the 0-0 and 0-40 treatment materials. In all treatments flax took up nearly all the nitrogen it required by 60 days after seeding. Little nitrogen was taken up after this date.

TABLE IX.

THE AMOUNT OF NITROGEN IN LBS. PER ACRE AT EACH HARVEST IN THE PLANT MATERIAL GROWN ON THE STUBBLE SOIL

Crop	Treatment	Harvest	Harvest	Harvest	Harvest	Harvest V	Harvest V	Seed	Nitrogen in the seed as a % of the total N. in the plant material at harvest V
		I	II	III	IV	Total	plant material other than seed		
Wheat	0-0	7.6	21.0	36.6	39.7	40.5	17.5	23.0	56.8
	0-40	8.2	28.1	46.4	52.0	39.8	16.6	23.2	58.3
	60-0	10.1	36.1	42.4	45.1	46.3	19.6	26.7	57.7
	60-40	12.8	44.7	56.9	60.0	53.1	22.7	30.4	57.3
Rapeseed	0-0	2.3	20.1	43.8	49.5	46.3	22.5	23.8	51.4
	0-40	2.5	24.4	41.8	64.5	45.3	17.1	28.2	62.3
	60-0	3.2	30.4	56.5	67.0	76.3	37.4	38.9	51.0
	60-40	3.0	33.4	82.6	96.8	74.9	30.4	44.5	59.4
Flax	0-0	3.9	21.1	31.7	35.0	36.2	14.5	21.7	59.9
	0-40	3.0	17.6	30.2	35.2	36.6	15.8	20.8	56.8
	60-0	4.4	28.5	41.1	48.6	48.9	21.8	27.1	55.4
	60-40	2.3	26.8	42.0	39.2	49.1	25.0	24.1	49.1

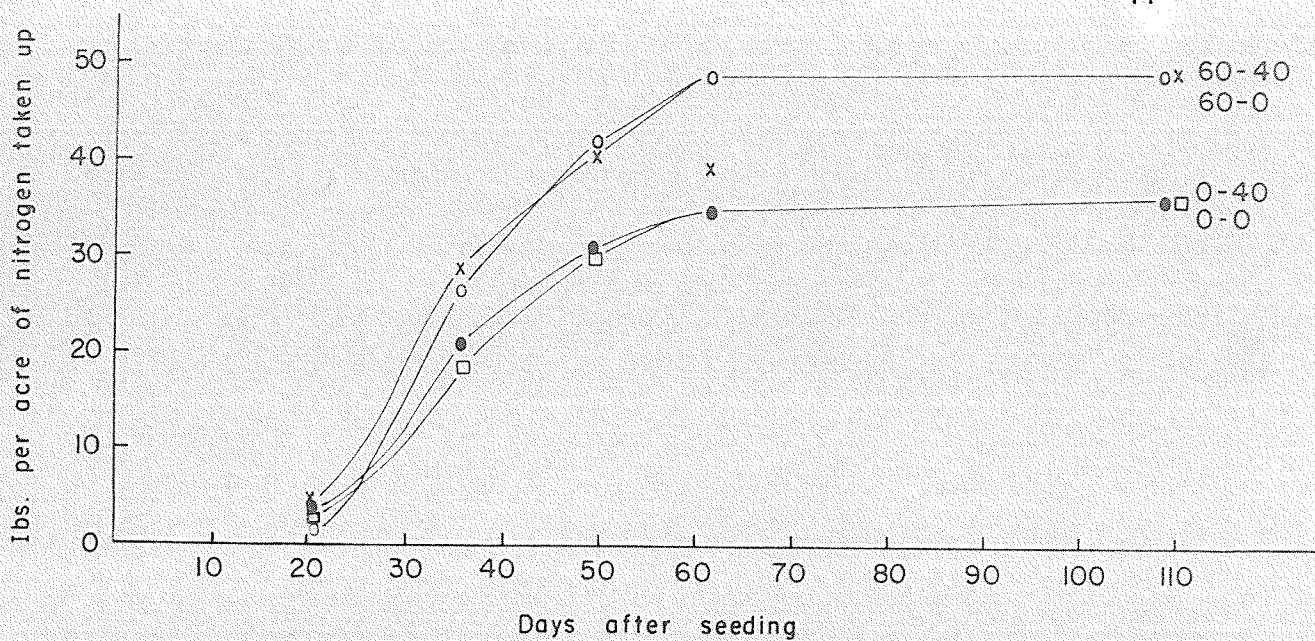


Figure 5. Nitrogen uptake for 60-40, 60-0, 0-40 and 0-0 treatment flax grown on stubble soil.

○ 60-40 ● 0-40
 × 60-0 □ 0-0

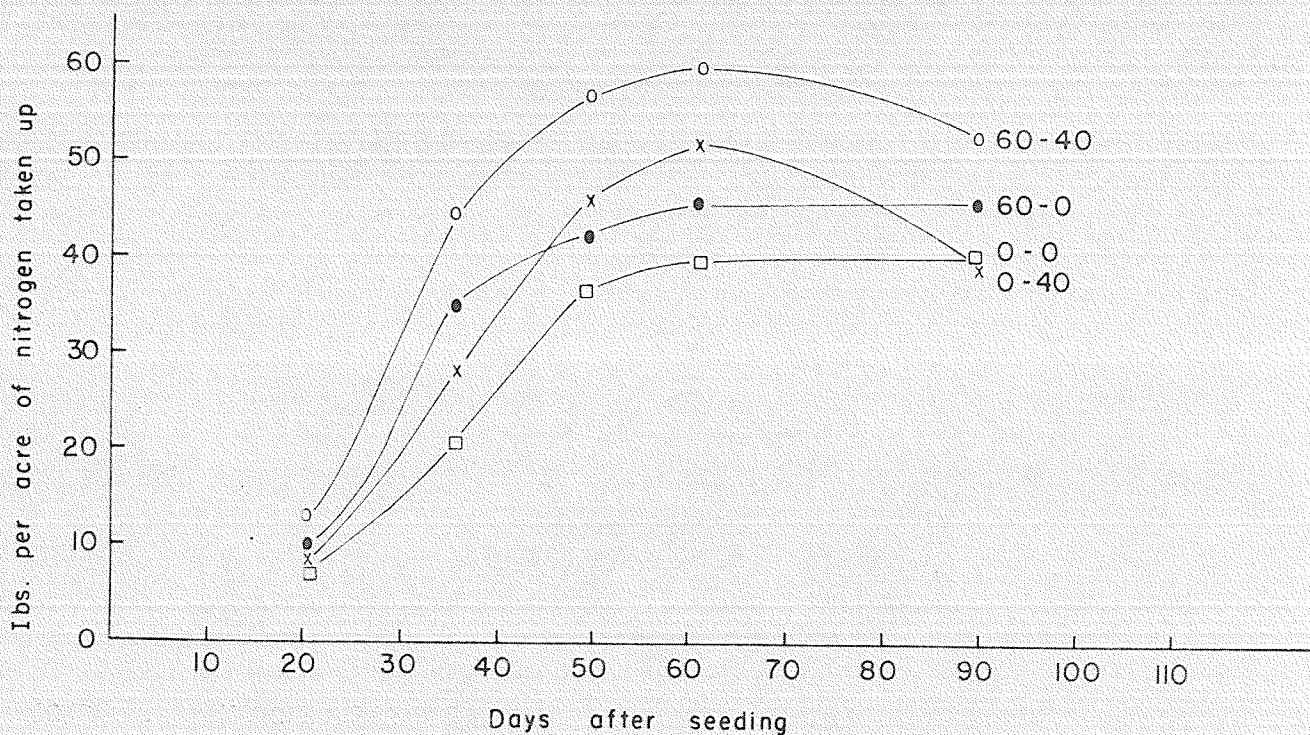


Figure 6. Nitrogen uptake for 60-40, 60-0, 0-40 and 0-0 treatment wheat grown on stubble soil.

○ 60-40 □ 0-0
 ● 60-0 × 0-40

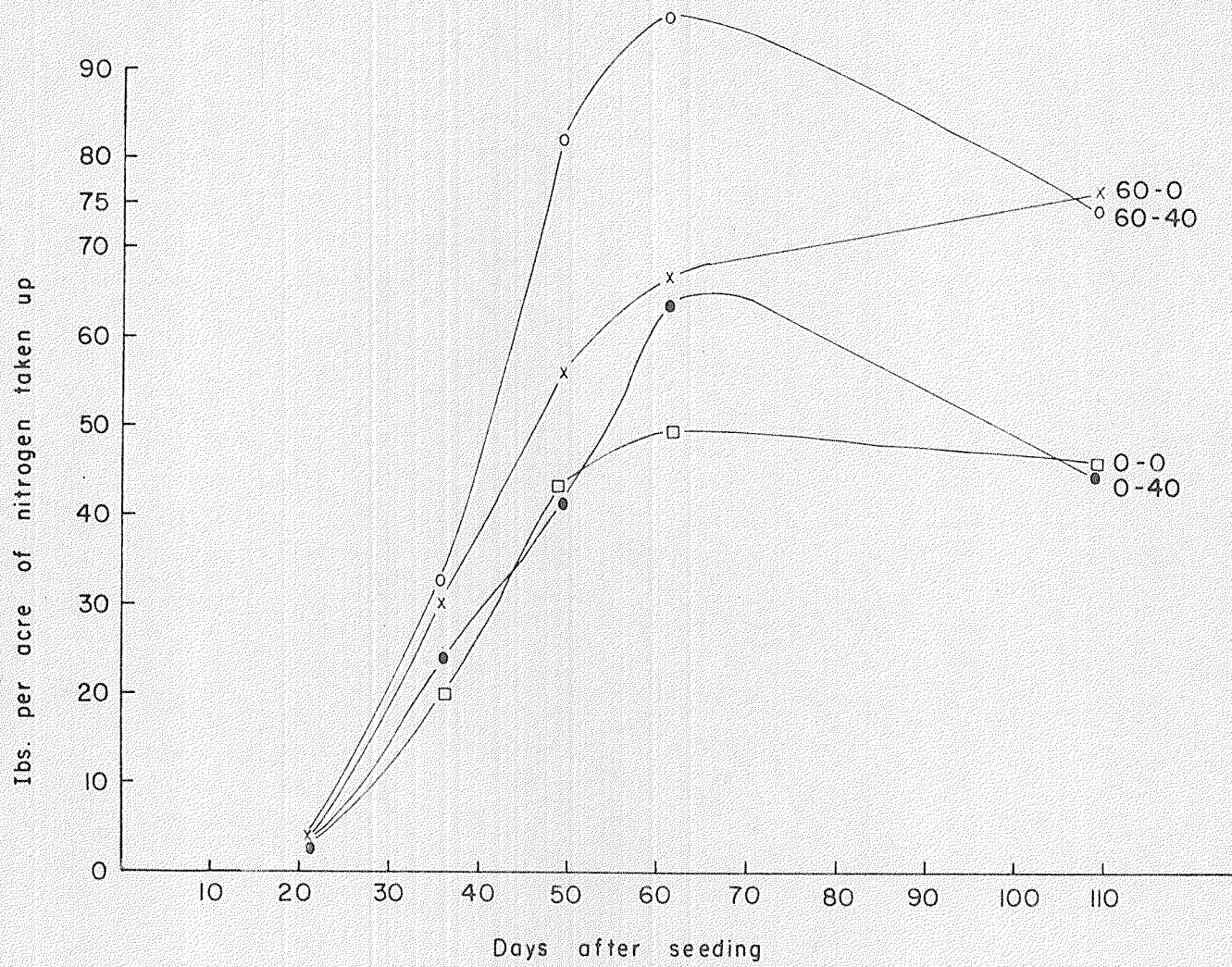


Figure 7. Nitrogen uptake for 60-40, 60-0, 0-40 and 0-0 treatment rapeseed grown on stubble soil.

Wheat took up about the same total amount of nitrogen as did flax. The 60-40 and 60-0 treatment total plant materials at harvest V contained 13 and 5 lbs. per acre more nitrogen respectively than did the 0-0 and the 0-40 treatment total plant materials. The graphs show that the treatments of wheat had taken up all the nitrogen they required for growth by 60 days after seeding. Beyond 60 days after seeding the 60-40 and 0-40 treatment plants lost approximately 10 lbs. per acre of nitrogen from their above ground portions. The 0-0 and 60-0 treatment plant materials neither gained nor lost nitrogen after that date. The 60-40 and 0-40 treatment rapeseed total plant materials at harvest V contained about 30 lbs. per acre more nitrogen than did the 0-0 and 0-40 treatment plant materials. The 60-40, 0-40 and 0-0 treatment plants satisfied their total nitrogen requirements by 60 days after seeding. After that date the 60-40 and 0-40 treatment plant materials each lost 20 lbs. per acre of nitrogen from their above ground parts. The 0-0 treatment plant material lost 4 lbs. per acre of nitrogen. The 60-0 treatment plants took up some nitrogen later than 60 days after seeding indicating that the supply of phosphorus available to those plants limited nitrogen uptake for at least a portion of the growing season. At harvest V the 60-0 treatment total plant material contained as much nitrogen as did the 60-40 treatment total plant material. These data indicate that although soil phosphorus became available to the plants slowly the quantity of phosphorus supplied during the growing season was sufficient to enable the 60-0 treatment plants to make as efficient use of the available

nitrogen as did the 60-40 treatment plants.

A very interesting observation concerning the wheat and rapeseed nitrogen utilization data is that the plant materials which lost sizable quantities of nitrogen from their above ground parts were those grown on the phosphorus fertilized treatments. The two crops lost different quantities of nitrogen, however, the quantities and rates of nitrogen loss by 0-40 and 60-40 treatment plant materials of each crop were the same. None of the flax plant materials lost nitrogen.

Figure 8 shows that rapeseed and wheat took up nitrogen at approximately equal rates until 40 days after seeding. Beyond this date the rate of nitrogen uptake by wheat decreased rapidly until 60 days after seeding. The rate of nitrogen uptake by rapeseed did not decrease appreciably until 55 days after seeding. Flax took up nitrogen at a rate approximately equal to that for wheat until 60 days after seeding. After this date flax plant material neither gained nor lost nitrogen.

On the average, 50-60 per cent of the nitrogen in the total plant material at harvest V was located in the seed. These data indicate that when placed under nitrogen stress the three crops employed approximately equal proportions of their total nitrogen for seed production.

Per cent phosphorus in the plant material

Total phosphorus analyses were conducted on all plant material

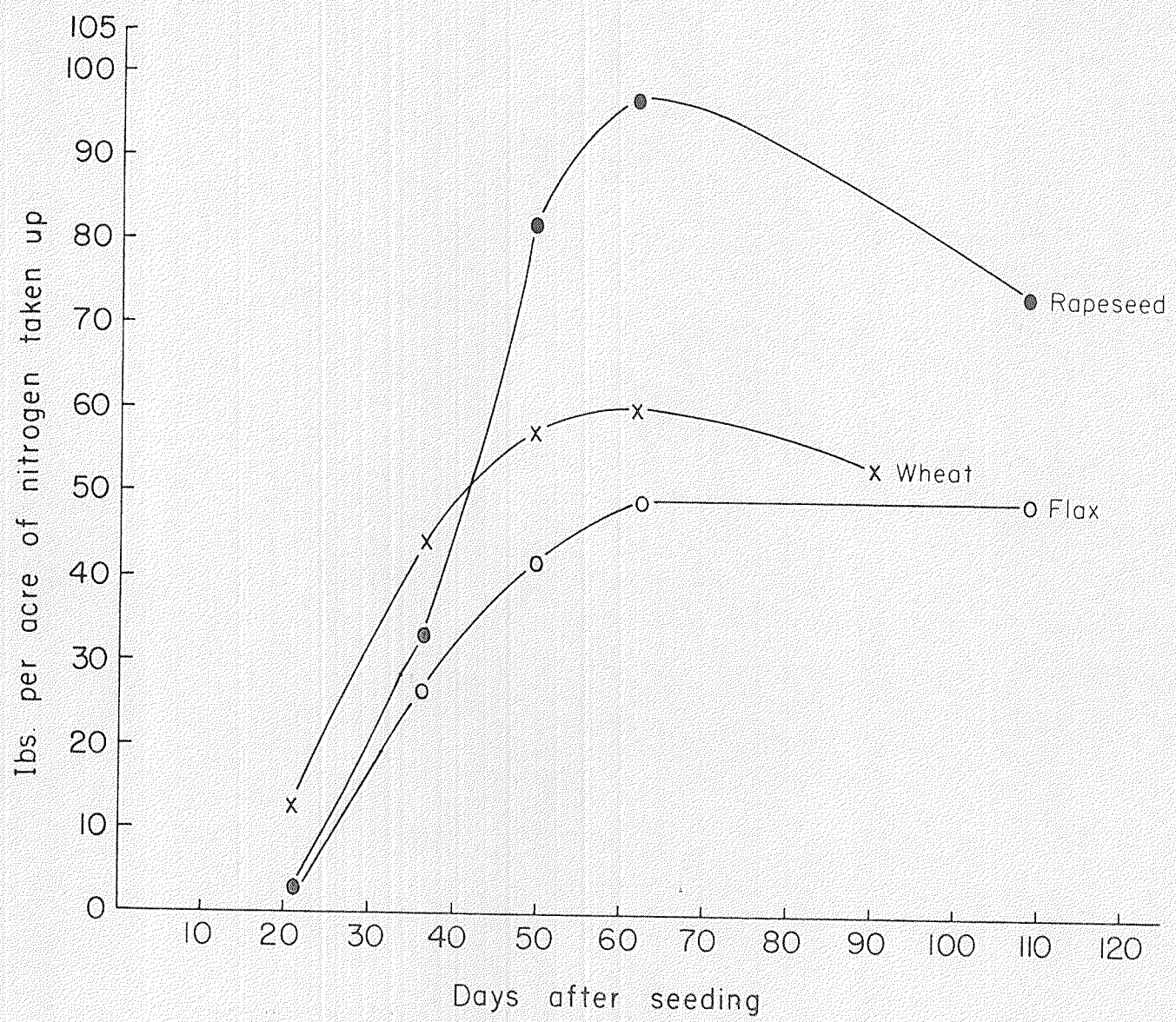


Figure 8. Nitrogen uptake for 60-40 treatment flax, wheat and rapeseed grown on stubble soil.

samples harvested from the fallow and stubble plots in order to determine the variations in the phosphorus contents of the plant materials as the crops grew and matured. The results of these analyses are expressed as the per cent phosphorus in the oven dry plant material and are listed in Tables X and XI respectively.

Fallow plot. The data in Table X indicate that as the crops grew and matured the phosphorus contents of their plant materials gradually decreased. The phosphorus contents of flax and rapeseed plant materials were approximately equal at corresponding harvest dates and were higher than those for wheat. Flax and wheat plant materials showed little variation in phosphorus content between the different fertilizer treatments. The phosphorus contents of rapeseed treated with phosphate fertilizer were definitely higher than those of the check or nitrogen fertilizer treatments. The phosphorus contents of the seed of rapeseed and flax were approximately equal. The 60-40 and 0-40 treatment seed of both crops had higher phosphorus contents than that of the 60-0 or 0-0 treatments. Wheat seed showed little variation in phosphorus content between fertilizer treatments. The phosphorus content of wheat seed was lower than that of rapeseed or flax seed.

Stubble plot. The per cent phosphorus in the plant materials of all crops grown on the stubble soil were lower than for the corresponding crops grown on the fallow soil. As was noted for the fallow plot data, the phosphorus contents in each of the plant materials continually decreased as the crops grew and matured. On the average,

TABLE X

THE PER CENT PHOSPHORUS AT EACH HARVEST IN THE PLANT MATERIALS GROWN ON THE FALLOW SOIL

Crop	Treatment	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V	Seed
Wheat	0-0	.33	.34	.24	.19	.12	.50
	0-40	.37	.36	.24	.21	.14	.52
	60-0	.35	.34	.24	.19	.13	.48
	60-40	.41	.36	.24	.20	.14	.50
Rapeseed	0-0	.47	.38	.27	.25	.14	.72
	0-40	.59	.47	.35	.33	.14	.80
	60-0	.46	.39	.26	.24	.13	.66
	60-40	.61	.47	.33	.32	.15	.76
Flax	0-0	.23	.41	.27	.23	.18	.73
	0-40	.32	.49	.25	.26	.20	.81
	60-0	.32	.51	.26	.23	.16	.73
	60-40	.24	.52	.29	.26	.21	.80

TABLE XI

THE PER CENT PHOSPHORUS AT EACH HARVEST IN THE PLANT MATERIALS GROWN ON THE STUBBLE SOIL

Crop	Treatment	Harvest I	Harvest II	Harvest III	Harvest IV	Harvest V	Seed
Wheat	0-0	.30	.24	.15	.13	.09	.45
	0-40	.36	.31	.17	.15	.07	.44
	60-0	.30	.24	.14	.13	.07	.38
	60-40	.41	.31	.16	.14	.09	.42
Rapeseed	0-0	.45	.28	.25	.24	.08	.61
	0-40	.65	.48	.30	.30	.10	.76
	60-0	.41	.28	.25	.24	.08	.59
	60-40	.59	.50	.29	.29	.09	.69
Flax	0-0	.33	.23	.15	.13	.11	.59
	0-40	.49	.31	.17	.15	.15	.67
	60-0	.35	.23	.12	.12	.10	.56
	60-40	.42	.30	.16	.15	.13	.64

the variations in phosphorus content between treatments are larger for the crops grown on the stubble soil than for those grown on the fallow soil. The large differences in phosphorus content between treatments are most noticeable early in the growing season and nearly disappear as the crops approach maturity.

The phosphorus contents of wheat and flax were similar at corresponding harvest dates and were somewhat lower than were those of rapeseed. The phosphorus contents of rapeseed and flax seed were similar and were higher than that of wheat. Whereas the phosphorus contents of rapeseed and flax seed varied widely between fertilizer treatments, wheat seed showed little variation in phosphorus content between fertilizer treatments.

Absolute amounts of phosphorus in the plant materials

Data for the fallow and stubble plots showing the absolute amounts of phosphorus in lbs. per acre in the plant materials at each harvest date and in the seed are listed in Tables XII and XIII respectively. Graphs showing a comparison of the phosphorus taken up at each harvest date plotted against days after seeding for the 60-40 treatments of each crop grown on the fallow and stubble soils are given in Figures 9 and 11 respectively. Graphs comparing the amounts of phosphorus used per weight of oven dry plant material produced by the 60-40 treatments of the three crops grown on the fallow and stubble soils are shown in Figures 10 and 12 respectively.

Fallow plot. Growing under the nearly ideal conditions

presented by the fallow plot, rapeseed proved to have a much greater capacity to utilize large quantities of phosphorus than had flax or wheat. The 60-40 treatment rapeseed took up 26 lbs. per acre of elemental phosphorus. The corresponding flax and wheat treatments each took up about 13 lbs. per acre of elemental phosphorus. Flax and wheat grown on the fallow soil showed little variation in phosphorus uptake between fertilizer treatments. The 60-40 and 0-40 treatment rapeseed plant materials contained larger quantities of phosphorus throughout the growing season than did the 0-0 or 60-0 treatment rapeseed. At harvest V the 60-40 and 0-40 treatment rapeseed plant materials contained 10 lbs. per acre more phosphorus than did the 0-0 plant material and 6 lbs. per acre more phosphorus than did the 60-0 plant material.

Figure 9 shows that the three crops differ in their phosphorus feeding habits. The rate of phosphorus utilization for flax was nearly constant throughout the growing season and was less than that for wheat or rapeseed. Wheat and rapeseed used phosphorus at about equal rates until 49 days after seeding. After that date the rate of uptake by wheat decreased until 62 days after seeding, by which time wheat had taken up all the phosphorus it required for growth and seed development. Rapeseed continued to use phosphorus at a rapid rate until 62 days after seeding. Beyond 62 days rapeseed took up phosphorus at a reduced rate until maturity.

Probably the most significant differences in the phosphorus feeding habits of the three crops are the differences in the stages

TABLE XII

THE AMOUNT OF PHOSPHORUS IN LBS. PER ACRE AT EACH HARVEST IN THE PLANT MATERIALS GROWN ON THE FALLOW SOIL

Crop	Treatment	Harvest	Harvest	Harvest	Harvest	Harvest V	Harvest V	Seed	Phosphorus in the seed as a % of the total P. in the plant material at harvest V
		I	II	III	IV	Total	plant material other than seed		
Wheat	0-0	.9	6.4	9.5	10.7	11.4	5.8	5.6	49.1
	0-40	1.2	6.3	10.0	11.9	13.0	7.2	5.8	44.6
	60-0	1.2	6.4	9.8	11.3	12.3	6.5	5.8	47.2
	60-40	1.5	7.0	10.3	12.3	12.7	7.0	5.7	44.9
Rapeseed	0-0	.4	4.0	5.5	9.2	17.0	9.7	7.2	42.4
	0-40	.5	4.6	10.1	16.7	27.1	12.2	14.8	54.6
	60-0	.4	4.4	8.4	11.1	22.3	10.8	11.5	51.6
	60-40	.6	6.6	10.6	16.5	25.8	12.9	12.9	50.0
Flax	0-0	.2	2.3	4.5	7.9	12.4	6.0	6.4	51.6
	0-40	.3	2.8	4.3	8.2	11.8	5.5	6.2	52.5
	60-0	.3	3.4	4.4	7.8	12.9	5.4	7.5	58.1
	60-40	.2	3.1	4.8	8.1	13.6	7.6	6.0	44.1

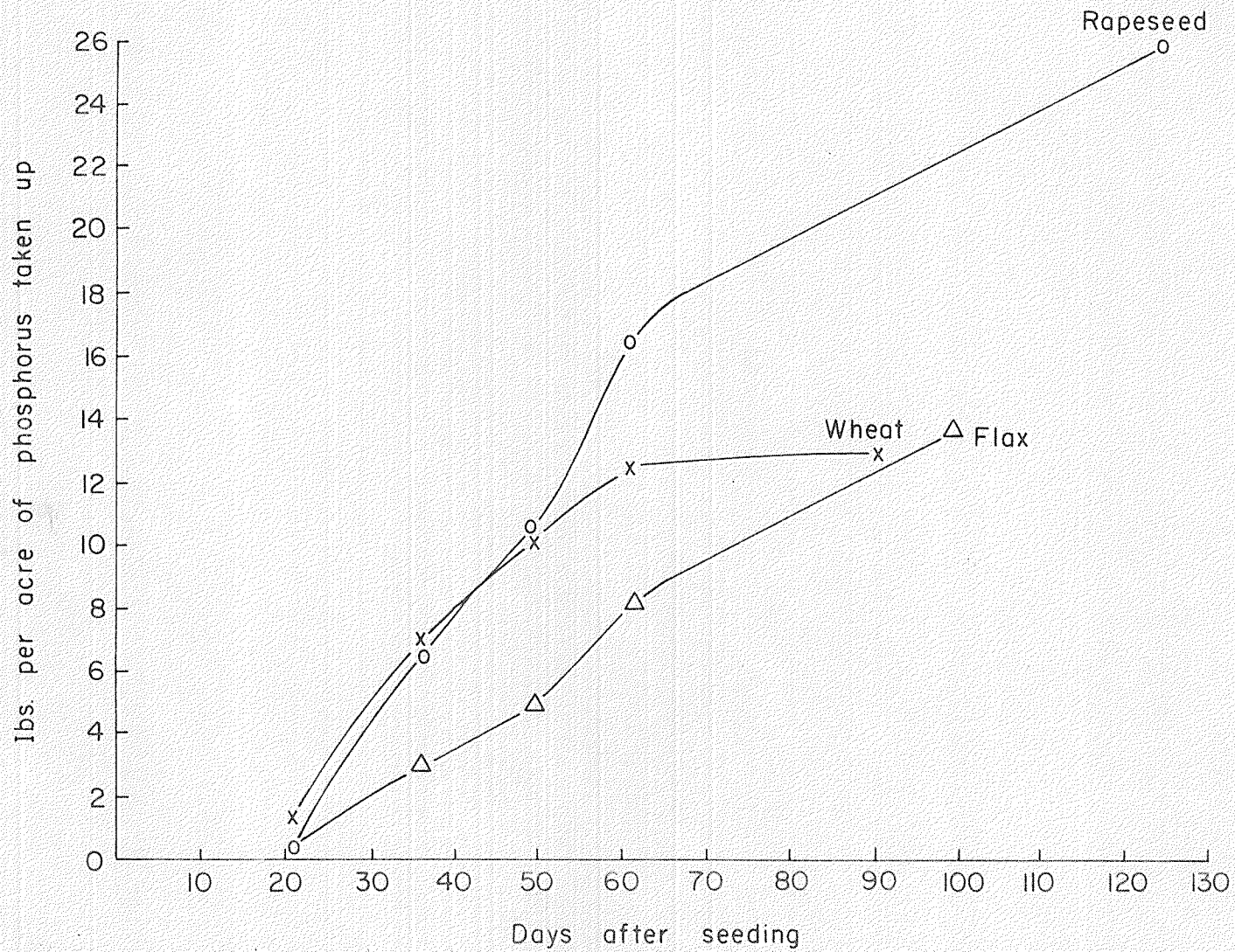


Figure 9. Phosphorus uptake for 60-40 treatment flax, wheat and rapeseed grown on fallow soil.

of growth during which phosphorus is taken up. Wheat took up about 80 per cent of its total phosphorus requirement before 49 days after seeding. During the same period rapeseed took up 40 per cent and flax took up 35 per cent of their total phosphorus requirements. Flax and rapeseed took up a large portion of their phosphorus late in the growing season. Wheat took up nearly all of its phosphorus early in the growing season.

The graphs in Figure 10 show that the ratio of the weight of phosphorus taken up to the weight of oven dry rapeseed plant material produced was nearly a constant value throughout the growing season. The ratio for wheat was equal to that for rapeseed until harvest II and then continued to decrease slowly until maturity. The ratio for flax was relatively large until harvest II after which time it decreased appreciably when the flax began to grow vigorously. After harvest III it remained nearly constant until maturity. Flax took up more phosphorus per weight of plant material produced after harvest IV than did rapeseed.

Approximately one-half of the phosphorus in the total plant material of all three crops at harvest V was located in the seed. The data show no distinct differences between crops or between treatments of crops in their efficiency of phosphate use in seed production.

Stubble plot. The NaHCO_3 -extractable phosphorus data shown in Table I indicate that the stubble soil contained somewhat less available phosphorus than did the fallow soil. The phosphorus utilization data show that the amount of phosphorus taken up by each crop

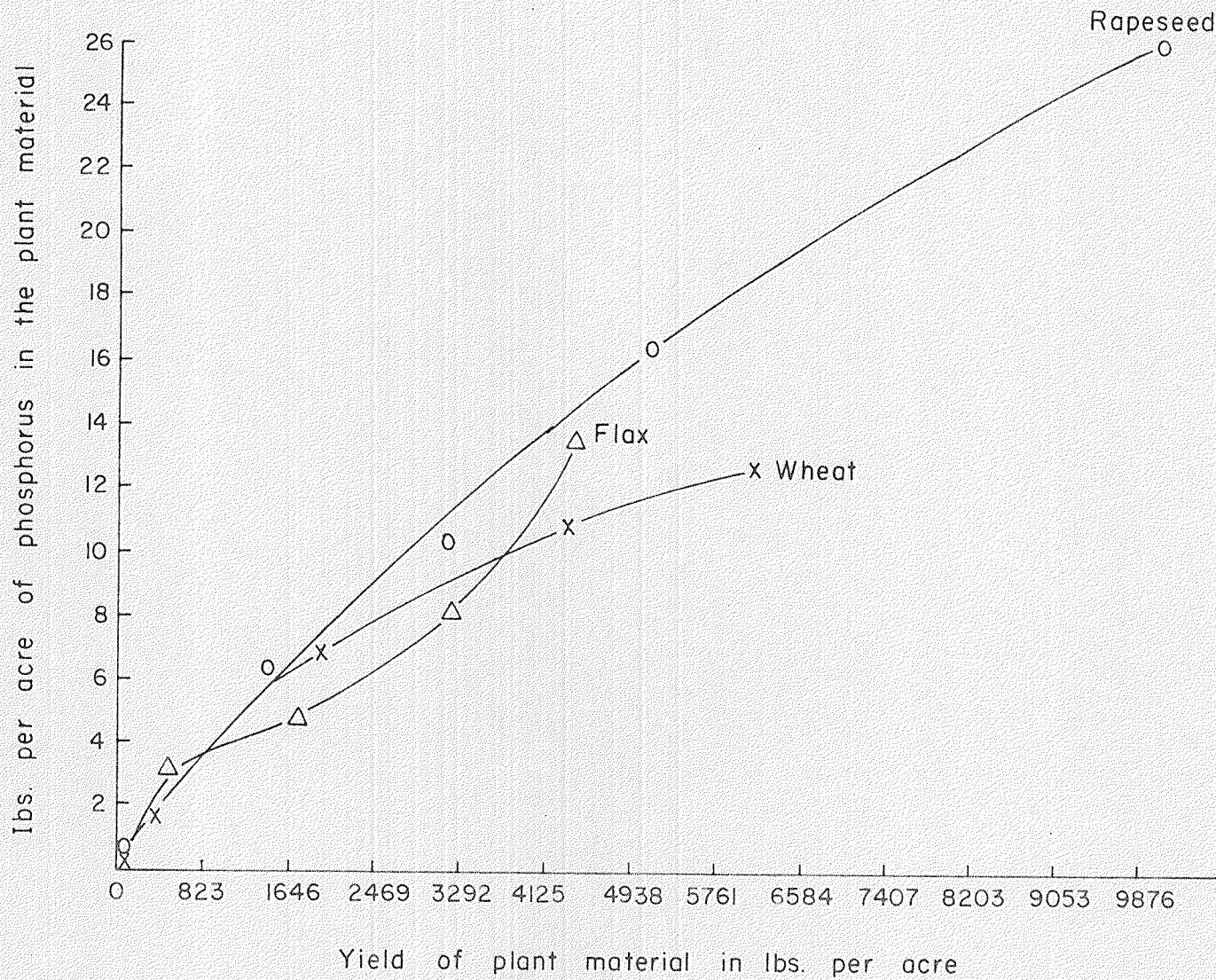


Figure 10. Relationship of phosphorus uptake to plant material production for 60-40 treatment flax, wheat and rapeseed grown on fallow soil.

TABLE XIII

THE AMOUNT OF PHOSPHORUS IN LBS. PER ACRE AT EACH HARVEST IN THE PLANT MATERIALS GROWN ON THE STUBBLE SOIL

Crop	Treatment	Harvest	Harvest	Harvest	Harvest	Harvest V	Harvest V	Seed	Phosphorus in the seed as a % of the total P. in the plant material at harvest V
		I	II	III	IV	Total	plant material other than seed		
Wheat	0-0	.5	2.1	3.3	4.1	5.9	2.1	3.9	66.1
	0-40	.7	2.9	4.3	5.9	5.6	1.7	3.9	69.6
	60-0	.6	2.5	3.3	3.9	5.1	1.7	3.4	66.7
	60-40	1.0	3.8	4.7	5.9	7.0	2.5	4.5	64.3
Rapeseed	0-0	.2	1.5	4.0	5.7	6.7	2.3	4.4	65.7
	0-40	.3	1.5	5.8	10.0	9.1	2.6	6.6	72.5
	60-0	.2	1.6	4.2	6.7	9.7	3.2	6.5	67.0
	60-40	.3	1.9	8.1	9.8	12.6	3.6	9.0	71.4
Flax	0-0	.3	1.5	2.6	3.3	5.5	2.0	3.5	63.6
	0-40	.3	1.5	2.6	3.6	6.3	2.6	3.7	58.7
	60-0	.3	1.6	2.4	3.5	5.9	2.3	3.6	61.0
	60-40	.2	1.9	2.9	3.6	6.4	2.5	3.8	59.4

grown on the stubble soil was about one-half that taken up by the same crop grown on the fallow soil. Grown on the fallow soil the 60-40 treatments of flax, wheat and rapeseed used 13.6, 12.7 and 25.8 lbs. per acre of phosphorus respectively. Grown on the stubble soil the 60-40 treatments of the same three crops used 6.4, 7.0 and 12.6 lbs. per acre of phosphorus respectively.

The phosphorus utilization data indicate that the various fertilizer treatments had little effect on the amount of phosphorus used by flax. At harvest V the 0-40 and 60-40 treatment plant materials contained only about one-half lb. and one lb. per acre more phosphorus than did the 60-0 and 0-0 treatment plant materials. Similar to flax, the 60-40 and 0-40 treatment wheat plant materials contained on the average only slightly more phosphorus than did the 60-0 or 0-0 treatment plant materials. By harvest V the 60-40 treatment wheat had taken up only one lb. per acre more phosphorus than had the 0-0 treatment wheat. It would appear that flax and wheat made very inefficient use of the added fertilizer phosphorus. The phosphorus fertilized treatments of rapeseed showed an increased uptake of phosphorus over the 60-0 and 0-0 treatments during the period from harvest II until maturity. The 60-40 treatment rapeseed plant materials at harvests III, IV and V contained approximately two times as much phosphorus as did the corresponding check treatment plant materials. The nitrogen fertilizer application of the 60-0 treatments increased the uptake of phosphorus by rapeseed probably because a more vigorously growing plant with a larger root system was developed on that treatment than

on the 0-0 treatment. It is suggested that had the supply of nitrogen not been a factor limiting phosphorus uptake the 0-40 treatment rapeseed would have taken up as much phosphorus as did the 60-40 treatment rapeseed. The phosphorus uptake data for rapeseed indicate that that crop made more efficient use of fertilizer phosphorus than did wheat or flax.

Figure 11 shows that flax grown on the stubble soil took up phosphorus at a constant rate throughout its growth. Wheat took up phosphorus fairly rapidly until harvest II, at which time the rate of uptake decreased and remained nearly constant until maturity. Previous to harvest II the 60-40 treatment rapeseed used phosphorus at about the same rate as did flax. After harvest II its rate of utilization increased rapidly to remain constant until harvest III. Subsequent to harvest III phosphorus was taken up slowly until maturity. The 0-0 treatment rapeseed took up phosphorus at a nearly constant rate approximately equal to that for wheat until harvest III, after which time phosphorus uptake slowed nearly to a stop. The 60-0 and 0-40 graphs, although not shown, are nearly identical shapes and lie intermediate between the 60-40 and 0-0 treatment graphs.

The graphs discussed above show that when grown on a soil having a relatively low level of available phosphorus wheat and flax took up phosphorus at a nearly constant low rate throughout the growing season, independent of the fertilizer treatment. Unfertilized rapeseed took up slightly more phosphorus than did wheat or flax and its rate of uptake was much greater prior to harvest IV than it

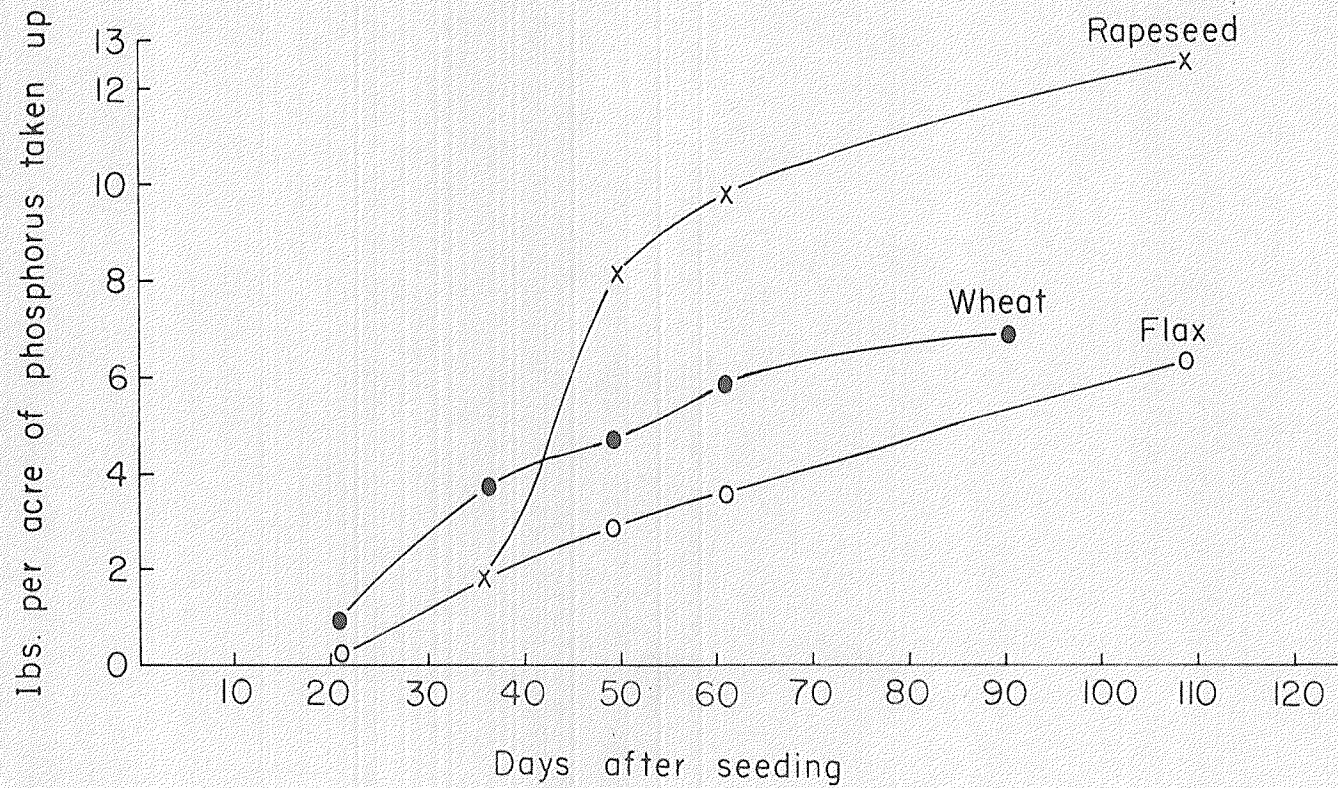


Figure 11. Phosphorus uptake for 60-40 treatment flax, wheat and rapeseed grown on stubble soil.

was later in the season. Rapeseed fertilized with nitrogen or phosphorus or a combination of the two showed an increase in rate of phosphorus utilization over that of the check treatment. The size of the increase depended upon the kind(s) of fertilizers added.

As was mentioned in the discussion of fallow plot data the crops differ with respect to the period of growth during which they take up phosphorus to satisfy their requirement. It was pointed out that flax and rapeseed grown on the fallow soil took up a large portion of their phosphorus later than 49 days after seeding. The same was not true of wheat. Wheat nearly satisfied its phosphorus requirement early in the growing season. The stubble plot data indicated that when grown on the stubble soil which had a relatively small amount of available phosphorus the 60-40 treatment wheat and rapeseed took up 67 and 64 per cents respectively of their total phosphorus complements prior to 49 days after seeding. The corresponding flax treatment took only 45 per cent of its total phosphorus requirement before the same date. The fallow and stubble plot data indicate that independent of the supply of available soil phosphorus flax takes up phosphorus at a slow rate throughout its growth. Wheat and rapeseed, it appears, have the ability to consume large amounts of readily available phosphorus in the early stages of their growth.

Figure 12 shows that the ratio of the weight of phosphorus taken up to the weight of oven dry plant material produced was constant throughout the growing season for rapeseed grown on the stubble soil. The same ratio for wheat was larger between harvests I and II

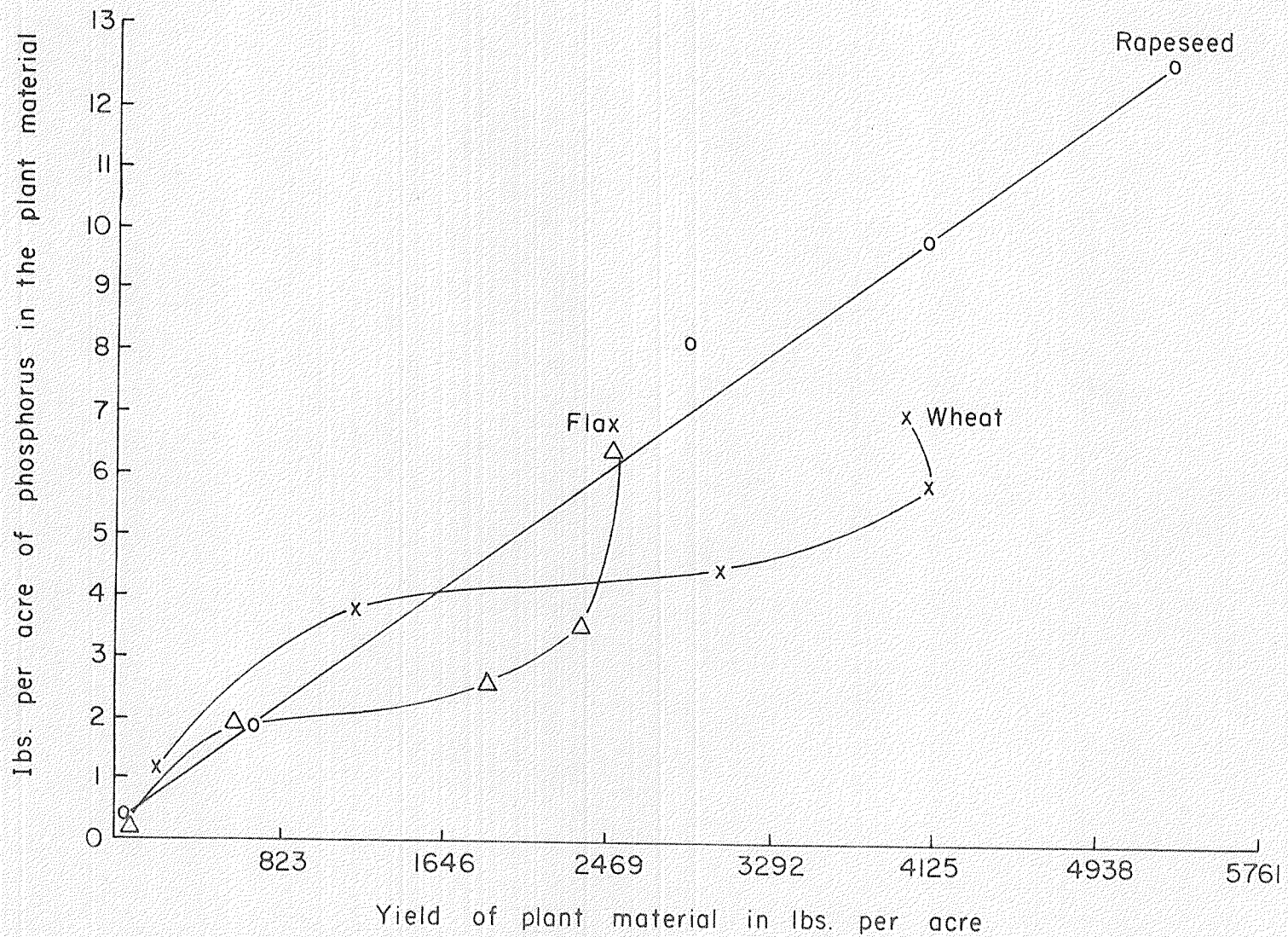


Figure 12. Relationship of phosphorus uptake to plant material production for 60-40 treatment flax, wheat and rapeseed grown on stubble soil.

than between harvests II and IV. Beyond harvest IV phosphorus uptake continued while at the same time the weight of dry plant material decreased. The graph for flax indicates, as did that for the fallow soil, that the ratio of the weight of phosphorus taken up to the weight of plant material produced was relatively large between harvests I and II, decreased after harvest II until harvest IV, and then increased after harvest IV due to continued phosphorus uptake coupled with a very small increase in the total weight of flax plant material.

Wheat and rapeseed both used between 65-72 per cent of the phosphorus in their total plant materials at harvest V for seed production. The proportion of the total phosphorus located in the flax seed was somewhat lower, varying between 58-63 per cent.

Summary and Conclusions

In an attempt to gain some knowledge concerning the growth habits and the nitrogen and phosphorus feeding habits of flax, wheat and rapeseed grown under field conditions, identical experiments were located on a fallow and a stubble soil in the Portage la Prairie, Manitoba area. The crops were subjected to four different fertilizer treatments; a check treatment (0-0), and phosphorus fertilizer alone treatment (0-40), a nitrogen fertilizer alone treatment (60-0), a treatment combining nitrogen and phosphorus fertilizers (60-40). Four harvests of plant material were taken at two week intervals during the growing season beginning three weeks after seeding. The fifth and final harvest was taken as each crop matured. Total yields

of plant material in lbs. per acre were calculated for all treatments of each crop at each harvest. The harvest V plant material samples were threshed and yields of seed were determined for each treatment of each crop. Total nitrogen and total phosphorus analyses were conducted on all plant material samples. The quantities of nitrogen and phosphorus in lbs. per acre of nutrient in the plant material were calculated for all treatments of the crops at each harvest. Concurrent with each harvest soil samples to a four foot depth were taken from the 0-40 treatment soils of each crop in an attempt to study the removal of nitrate nitrogen and moisture from the soil and the extent of root development for each of the crops at each of the five harvest dates.

Rapeseed produced larger yields of oven-dry plant material than did wheat and wheat produced larger yields than did flax. When confronted with plentiful supplies of moisture and nutrients rapeseed expressed a much greater capacity to produce large yields of plant material than did the other two crops.

Wheat initially grew more quickly than did rapeseed or flax and completed its growth by about 60 days after seeding. The rate of growth of rapeseed was initially slow, but it equalled that of wheat after harvest II. Beyond 60 days after seeding rapeseed continued to grow at a somewhat reduced rate until maturity. Throughout the growing season flax grew more slowly than did rapeseed or wheat.

Rapeseed showed greater responses to nitrogen and phosphorus fertilizers applied alone and in combination than did wheat or flax.

The phosphorus fertilizer applications decreased the germination of flax seed resulting in reduced yields of plant material and seed from these treatments.

The supply of nitrogen in the fallow soil was plentiful. Rapeseed grown on that soil used much larger quantities of nitrogen than did wheat or flax. When grown on the stubble soil in which nitrogen was a factor limiting plant growth rapeseed took up only slightly more nitrogen than did the other two crops. Rapeseed made more efficient use of fertilizer nitrogen added to the stubble soil than did wheat or flax.

Wheat took nitrogen up rapidly during the early part of its growing season and had satisfied its total requirement by 60 days after seeding. Rapeseed took up nitrogen at a rate approximately equalling that of wheat prior to harvest II and exceeding that of wheat after harvest II. Rapeseed grown on the fallow soil continued to take up nitrogen until maturity. Flax took nitrogen from both soils more slowly than did rapeseed or wheat, and approximately satisfied its total nitrogen requirement by 60 days after seeding. An interesting fact concerning the rapeseed and wheat data is that all treatments of wheat grown on the fallow soil and the 60-40 and 0-40 treatments of wheat and rapeseed grown on the stubble soil lost nitrogen from their above ground parts subsequent to 60 days after seeding. None of the flax plant materials lost nitrogen.

Rapeseed used two times as much phosphorus from the 60-40 treatment fallow soils in which the supply of phosphorus was plentiful

as did wheat or flax. When grown on the stubble soil in which the supply of phosphorus was a factor limiting plant growth rapeseed obtained slightly more phosphorus than did the other two crops. Rapeseed made much more efficient use of fertilizer phosphorus added to the stubble soil than did wheat or flax.

Rapeseed and wheat grown on the fallow soil took up phosphorus at approximately equal rates until harvest III, after which time the rate of phosphorus uptake by wheat decreased. By harvest IV wheat had satisfied its total phosphorus requirement. Rapeseed continued to take up phosphorus at a rapid rate until harvest IV. Beyond that date the rate of phosphorus uptake by rapeseed decreased and remained constant until maturity. Throughout the growing season flax used phosphorus at an approximately constant rate somewhat less than those of wheat or rapeseed.

Wheat and flax grown on the fallow soil took up phosphorus at nearly constant low rates throughout their growth. Rapeseed took phosphorus up at a relatively rapid rate during the period between harvests II and III. Beyond harvest III the rate of phosphorus uptake decreased and remained approximately constant until maturity.

The phosphorus utilization data for both plots showed that whereas wheat and rapeseed have capacities to take up large quantities of phosphorus in a short period of time, flax takes up phosphorus at a constant low rate throughout the growing season independent of the supply of available phosphorus.

The intended study of the rates and extents of root development

by the three crops was made impossible by the frequent heavy rains which fell on the plots during the summer resulting in excessive movement of nitrate nitrogen in the soil profile and practically no depletion of soil moisture at any depth.

On the basis of the field data presented several conclusions were drawn concerning the growth habits and the nutrient requirements of rapeseed, wheat and flax.

When grown on a soil having abundant supplied of nitrogen, phosphorus and moisture, rapeseed takes up much larger quantities of nitrogen and phosphorus and produces larger yields of plant material than does wheat or flax. Flax takes up the least nitrogen and produces the least plant material of the three crops. Flax and wheat take up approximately equal quantities of phosphorus.

When grown on a soil in which the supply of moisture is plentiful and the supplies of nitrogen and phosphorus are factors limiting plant growth, rapeseed is able to remove slightly more nitrogen and phosphorus from the soil than is wheat or flax and it produces somewhat more plant material than can the other two crops. Flax produces the least plant material, even though wheat and flax take up approximately equal quantities of nitrogen and phosphorus. Rapeseed makes more efficient use than does wheat or flax of nitrogen and phosphorus added to the soil in the form of fertilizers.

Wheat initially grows more quickly than does rapeseed or flax and completes its growth by about 60 days after seeding. Rapeseed initially grows very slowly, however, its rate of growth increases

until it equals that of wheat at about five weeks after seeding. The growth rate of rapeseed remains constant during the five to nine week period and then decreases somewhat to remain approximately constant until maturity. Flax grows more slowly and at a more nearly constant rate than does rapeseed or wheat.

In general, the rates of uptake of nitrogen by wheat, rapeseed and flax and the rates of uptake of phosphorus by wheat and rapeseed are largest during the period between three to nine weeks after seeding. Beyond nine weeks after seeding nitrogen and phosphorus uptake by these crops either continues at a reduced rate or completely stops. Flax takes phosphorus up at an approximately constant rate throughout its growth. Whereas wheat and rapeseed grown on a phosphate deficient soil take up nearly all of their phosphorus prior to nine weeks after seeding, flax takes up approximately one-half of its phosphorus later than this date.

GREENHOUSE EXPERIMENT I

Materials and Methods

A greenhouse experiment similar to that conducted by Webber (33) was designed to study and compare the phosphorus feeding habits of flax, oats and rapeseed and to determine whether any of these crops specifically affect the availability of soil phosphates. The experiment consisted of growing four treatments of three crops on one soil. Each treatment was replicated four times.

Manitoba contains large areas of high-lime soils. The earlier greenhouse experiment conducted by Webber (33) indicated that the native soil phosphorus in non-calcareous soils is most available to flax, less available to oats and least available to rapeseed. It was decided that a study to compare the availabilities of native soil phosphorus to the same three crops should be conducted on a high-lime soil.

Soil for the experiment was obtained from the 0"-6" layer of a Balmoral series soil (26) situated in the Teulon area. A characterization of the soil is given in Table XIV.

The soil was air dried and was put through a one-half inch wire mesh to remove any large clods. The clods were broken into smaller fragments and were mixed thoroughly with the fine material. 1800 gms. of air dry soil was added to each of the one-half gallon glazed porcelain pots in which the crops were to be grown. A total of 56 pots was

TABLE XIV
SOME CHARACTERISTICS OF THE SOIL EMPLOYED IN THE GREENHOUSE EXPERIMENT

pH	7.8
Conductivity of satn. extract (mmhos per cm.)	.66
Texture	SiCL
% organic carbon	5.14
% organic matter	8.86
% inorganic carbonate	27.91
CaCO ₃ equivalent (%)	46.55
NaHCO ₃ -extractable phosphorus (ppm)	8.4
Exchangeable potassium (ppm)	715.0
% hygroscopic moisture	6.0
% moisture at field capacity	42.5

prepared. Field capacity and hygroscopic moisture determinations were conducted to determine the weight of water required to moisten 1800 gms. of the air dry soil to field capacity.

The four treatments in the experiment were: treatment I, a check treatment (no fertilizer added); treatment II, a fertilizer treatment in which radioactive phosphate fertilizer was banded into the soil; treatment III, a fertilizer treatment in which radioactive phosphate fertilizer was mixed throughout the soil and treatment IV, a fertilizer treatment in which non-radioactive phosphate fertilizer was mixed throughout the soil coupled with a band of radioactive phosphate fertilizer.

At seeding time 20 ml. of a solution containing 1 uc of P32 per ml. was mixed thoroughly throughout each of the check treatment soils. This was accomplished by adding the carrier free P32 solution to the quantity of water required to moisten the soil to field capacity. The soil and water were then added to the porcelain pots in successive small increments. Adding P32 to the check treatment soils made possible a measurement of the exchangeable phosphorus in the soil. The amount of phosphorus added as P32 was so small that it did not change the phosphorus status of the soil insofar as the growing plants were concerned.

A 10 ml. aliquot of activated phosphate fertilizer solution containing 10 ppm of phosphorus was banded one and one-half inches below the surface of each of the treatment II soils at seeding time. Banding activated phosphate fertilizer into the soil made possible

a determination of "A" values for the soil as measured by each of the three crops.

A 20 ml. aliquot of the activated phosphate fertilizer solution containing 20 ppm of phosphorus was mixed thoroughly throughout each of the treatment III soils at seeding time. This was accomplished by adding the activated fertilizer solution to the quantity of water required to moisten the soil to field capacity. The soil and water plus fertilizer were then added to the porcelain pots in successive increments. Fertilizer treatment III made possible the determination of a second type of "A" value for the soil as measured by each of the crops.

Prior to seeding, 20 ppm of phosphorus in the form of finely granulated KH_2PO_4 was mixed throughout each of the treatment IV soils. A thorough mixing was accomplished by spreading each 1800 gm. portion of soil in a thin layer over a sheet of paper. 0.158 gm. of KH_2PO_4 was spread as evenly as was possible over the layer of soil. The soil plus fertilizer was rolled on the paper for five minutes. At seeding time 10 ml. of activated phosphate fertilizer was banded into the soil one and one-half inches below the surface. Treatment IV was designed to determine how and to what extent mixing fertilizer phosphate throughout the soil would affect the treatment II "A" value determination.

Addition of phosphorus as KH_2PO_4 required that appreciable quantities of potassium were simultaneously added to the fertilized treatment soils. At seeding time the level of available potassium

in the treatment I, II and III soils was made equivalent to that of the treatment IV soil by adding a predetermined quantity of a KCl solution which contained .5148 gm. KCl per litre of solution.

All crops were seeded on October 16. The seeds were placed approximately one-half inch below the soil surface and the soil was moistened to field capacity. The weight of each pot plus soil at field capacity was calculated and optimum moisture conditions for plant growth were maintained by adding a sufficient weight of water to moisten the soil to field capacity every two or three days.

The plants first appeared on October 19. One week later the plant population of all but eight pots of flax was reduced to leave only the four healthiest and best spaced plants. Of the remaining eight pots of treatment II flax, two groups of four pots containing populations of eight and twelve flax plant respectively were prepared. It was felt that if populations of flax larger than four plants were grown, yields of dry flax plant material would more nearly equal those for oats and rapeseed. Nearly equal yields of dry plant material should lend basis for the direct comparison of flax, oat and rapeseed "A" values.

Wire supports were installed in some pots after three weeks of growth to maintain the oats and flax in an upright position.

The crops were harvested on December 3, 48 days after seeding. The plants were cut off at the soil surface and were chopped in approximately one-quarter inch lengths into paper bags to air dry. When air dry, the plant material was oven-dried at 90° C. for several hours, then cooled and weighed. The oven dry plant material was

finely ground and a representative sample was wet ashed. Aliquots of the ash solution were taken for total phosphorus analysis and radioactive counting.

Results and Discussion

The yields of plant material in gms. of oven dry weight are given in Table XV.

Yield of plant matter

The yields of flax plant material for all treatments were much smaller than the yields of either oats or rapeseed. All treatments of oats and rapeseed produced more than one and one-half gms. of oven dry plant matter and many produced nearly three grams. In contrast, where there was a population of twelve flax plants in treatment II the average yield of oven dry plant material was less than one gm. It is interesting to note that for the three populations of flax grown in treatment II there is a nearly linear relationship between size of plant population and weight of dry matter produced.

Flax showed no response to the treatment II band application of phosphate fertilizer, however, it responded to phosphate mixed throughout the soil as it was applied in treatments III and IV. Oats and rapeseed produced approximately equal quantities of oven dry plant material. Both crops showed good responses to phosphate fertilizer independent of the method of application.

TABLE XV
EFFECT OF FERTILIZER TREATMENT ON THE YIELD OF PLANT MATERIAL, PER CENT YIELD
AND THE PER CENT PHOSPHORUS IN THE PLANT MATERIAL

Crop	Treatment	Wt. oven dry plant matter gms.	Yield check treatment		Total P. in plant matter as a % of the plant weight
			Yield fertilized treatment	$\times 100 =$ per cent yield	
Flax	I	.38			.49
	II ₄	.32		118.8	.57
	II ₈	.71			.46
	II ₁₂	.92			.40
	III	.45		84.4	.48
	IV	.44		86.4	.59
Oats	I	1.80			.35
	II	2.34		76.9	.32
	III	2.40		75.0	.36
	IV	2.39		75.3	.36
Rapeseed	I	1.56			.25
	II	2.75		56.7	.31
	III	2.90		53.8	.36
	IV	2.81		55.5	.37

Per cent yield

The per cent yield data were determined by calculating the yield of the check treatment as a percentage of the yields of the fertilized treatments. These data indicate that flax showed differences in response to fertilizer phosphate depending upon the method of fertilizer application and that flax, oats, and rapeseed differ in the magnitude of their response to fertilizer phosphate. Flax responded to phosphate mixed throughout the soil but did not respond to phosphate applied in a band. Oats and rapeseed responded as well to the band application of phosphate as to the thoroughly mixed phosphate application.

The magnitude of crop response to fertilizer phosphate decreased in the order rapeseed, oats, flax. The yields of plant matter from the fertilized treatments of rapeseed were about two times as great as from the check treatments. The oat check treatments produced a yield approximating three-fourths that of the fertilizer treatments. Flax showed much smaller responses to the fertilizer phosphate applications of treatments III and IV than did oats and rapeseed.

Per cent phosphorus in the plant material

In comparison to the oat and rapeseed plant materials, flax contained a high percentage of phosphorus. Treatment II data indicate that with increased plant population the percentage of phosphorus in flax plant material decreased. It would appear from the treatment II, having a four plant population, and treatment IV data that when the

supply of phosphorus is large in comparison to the amount required for plant growth, flax makes luxury use of that nutrient.

The percentage of phosphorus in the oat and rapeseed plant materials obtained from identical fertilizer treatments were similar except for the check treatments. The check treatment oats and rapeseed contained .35 and .25 per cent phosphorus respectively. The check yields for both crops were considerably less than any of the fertilized treatment yields, indicating that both crops were subjected to a phosphate stress. The fact that oats was able to produce a larger amount of plant matter having a higher phosphate content than was rapeseed under these conditions indicates that the soil phosphorus was more available to oats than to rapeseed.

Phosphorus Utilization Data

Phosphorus utilization data for flax, oats and rapeseed, including total uptake of phosphorus in mgm., uptake of soil phosphorus mgm., uptake of fertilizer phosphorus mgm., and per cent utilization of fertilizer phosphorus added to the soil, are listed in Table XVI.

Total uptake of phosphorus

The total amount of phosphorus taken up by flax was so small for all treatments that it was probably determined by plant requirement rather than by phosphorus availability. It is suggested that phosphorus availability was at no time a factor limiting the growth of flax.

TABLE XVI

PHOSPHORUS UTILIZATION DATA FOR FLAX, OATS AND RAPESEED

Crop	Treatment	Total phosphorus uptake mgm.	Soil phosphorus uptake mgm.	Fertilizer phosphorus uptake mgm.	Per cent utilization of fertilizer phosphorus
Flax	I	1.85	1.85		
	II ₄	1.83	1.34	.49	2.7
	II ₈	3.27	2.33	.94	5.18
	II ₁₂	3.67	2.68	.99	5.48
	III	2.17	1.32	.85	2.35
	IV	2.60	2.17	.43	2.41
Oats	I	6.23	6.23		
	II	7.56	4.93	2.63	14.61
	III	8.54	5.54	3.00	8.33
	IV	8.57	6.63	1.94	10.77
Rapeseed	I	3.93	3.93		
	II	8.48	3.68	4.80	26.67
	III	10.30	6.57	3.73	10.40
	IV	10.44	6.12	4.32	23.40

Oats took up more phosphorus from the fertilized treatments than from the check treatment and slightly more phosphorus from treatment III and IV in which the fertilizer had been mixed throughout the soil than from treatment II which contained only a band of phosphate fertilizer.

Whereas oats was able to obtain nearly as much phosphorus from the check treatment as from treatment II, rapeseed obtained more than two times as much phosphorus from treatment II and two and one-half times as much phosphorus from treatments III and IV as from the check treatment.

Uptake of soil phosphorus

In comparison to the quantities of soil phosphorus taken up by oats and rapeseed, flax took up very little soil phosphorus. For all treatments except treatment III, oats took up more soil phosphorus than did rapeseed. Treatment III rapeseed took up a larger total quantity of phosphorus than did treatment III oats and it is suggested that this may explain the seemingly anomalous results. The ratios of soil phosphorus to total phosphorus in the two plant materials are identical (.64).

Oats was able to remove nearly two times as much phosphorus from the check treatment soil as was rapeseed. These data indicate that under the existing experimental conditions oats was a stronger soil phosphorus feeder than was rapeseed.

Uptake of fertilizer phosphorus

The quantities of fertilizer phosphorus used by flax were small for all treatments. The treatment II twelve plant population used less than 5.5 per cent of the phosphorus added.

Field data indicate that under conditions in which the supply of nitrogen and available phosphorus is plentiful flax uses only a very limited amount of phosphorus before the seven week stage of growth. Had the flax in the greenhouse experiment been grown for a longer period of time it may have made more efficient use of fertilizer phosphorus.

Oats and rapeseed were much more efficient users of fertilizer phosphorus than was flax. Rapeseed used slightly more treatment III fertilizer phosphorus than did oats because, as was previously stated, rapeseed consumed a larger total quantity of phosphorus. The ratios of fertilizer phosphorus to total phosphorus in the plant materials are identical for the two crops.

The phosphate utilization data for treatments II and IV in which fertilizer phosphorus was banded into the soil, point out a rather striking difference between the phosphorus feeding habits of oats and rapeseed. It will be recalled that in treatment II, 10 ppm of phosphorus was banded one and one-half inches below the soil surface. Rapeseed utilized just less than two times as much phosphorus from the fertilizer band as did oats. In treatment IV, 20 ppm of phosphorus was mixed throughout the soil accompanied by a phosphate band containing 10 ppm of phosphorus placed one and one-half

inches below the soil surface. Treatment IV data show that rapeseed used slightly more than two times as much phosphorus from the band as did oats. It would appear that even though there was a large amount of available phosphorus mixed throughout the soil, rapeseed preferred to obtain its phosphorus from the fertilizer band in which there was a relatively higher phosphate concentration than in the remaining soil. Adding phosphate fertilizer throughout the soil increased the total amount of phosphorus taken up by rapeseed without appreciably affecting the per cent utilization of banded fertilizer phosphorus. The same fertilizer treatment decreased by one-quarter the utilization of banded phosphorus by oats. Oats does not show the same preference for phosphorus from fertilizer band as does rapeseed.

Treatment II data suggested that oats was better able to obtain phosphorus from a medium having a low phosphate concentration than was rapeseed. The fact that mixing fertilizer phosphorus throughout the treatment IV soil increased the utilization of soil phosphorus more and decreased the utilization of band phosphorus less for rapeseed than for oats indicated that rapeseed has a larger potential to use phosphorus than has oats.

"A" Value Data

The "A" value data are listed in Table XVII.

"A" value

An "A" value is a measure of the quantity of available nutrient in a soil in terms of a fertilizer standard. The measurement is

TABLE XVII
 "A"¹ VALUES (MGM. P.)

Crop	Treatment II "A" value	Treatment IV "A" value	Treatment II "A" value
Flax 4	54.0	92.0	75.0
Flax 8	46.0		
Flax 12	44.7		
Oats	34.2	62.6	66.8
Rapeseed	13.8	26.0	63.0

¹ "A" value = $\frac{\text{mgm. soil P in plant material}}{\text{mgm. fertilizer P in plant material}} \times \text{mgm. fertilizer P added to soil}$

based on the assumption that when confronted with two sources of a nutrient growing plants will absorb from each source in proportion to the respective quantities of nutrient available.

For treatments II, III and IV the quantity of available phosphorus in the soil was measured in terms of a KH_2PO_4 standard. P32 tracer was added to the KH_2PO_4 to enable differentiation between soil and fertilizer phosphorus in the plant materials. The radioactive KH_2PO_4 in solution form was banded into the treatments II and IV soils one and one-half inches below the soil surface and was mixed throughout the treatment III soil at seeding time.

Differences between treatments II and IV "A" values determined with several crops grown on a single soil would suggest that the crops have different phosphorus feeding habits and could imply differences between the crops in their abilities to feed on soil phosphorus. Differences between treatment III "A" values determined with several crops grown on a single soil imply differences between the soil phosphorus feeding powers of the crops.

The treatment II "A" values were a measure of the amount of native soil phosphorus readily available for use by flax, oats and rapeseed. The "A" values determined with the four, eight and twelve plant populations of flax were similar and it was concluded that the measurement does not vary appreciably with differences in plant population. The "A" values determined with the three crops decreased in the order flax, oats, rapeseed, indicating that the native soil phosphorus was most available to flax, less available to oats and least

available to rapeseed.

Twenty ppm (i.e. 36 mgm.) of phosphorus was mixed throughout each 1800 gm. portion of treatment IV soil to determine how and to what extent adding phosphate fertilizer would affect the treatment II "A" value measurement. The treatment IV "A" values for each crop exceeded the corresponding treatment II "A" values by a factor of two. These data suggest that, as was the case for the native soil phosphorus, fertilizer phosphorus mixed throughout the soil was most available to flax, less available to oats, and least available to rapeseed.

The treatment III "A" values determined with oats and rapeseed were approximately equal. The flax "A" value was larger than those for the other two crops. These data support the previously stated suggestion that soil phosphorus was more available to flax than to oats or rapeseed.

Exchangeable phosphorus data

The exchangeable phosphorus value data are listed in Table XVIII.

Exchangeable phosphorus value

The exchangeable phosphorus value determined with each crop is a measure of the reservoir of labile soil phosphorus which is available for plant use or which could become available to plants as they grow and utilize phosphorus. Appreciable differences between exchangeable phosphorus values determined with several crops grown

TABLE XVIII
EXCHANGEABLE PHOSPHORUS VALUES¹ (MGM. P.)

	Treatment I	Treatment III
Flax	94.1	110.8
Oats	86.0	107.8
Rapeseed	115.7	100.8

¹ Exchangeable phosphorus = $\frac{\text{P32 added to the soil}}{\text{P32 in the plant material}} \times \text{mgm. P31 in the plant material}$

on a single soil would indicate that the amounts of phosphorus available for use by the crops were different.

Exchangeable phosphorus values were determined with each of the crops grown in treatments I and III. Since 20 ppm (i.e. 36 mgm.) of phosphorus was mixed throughout the treatment III soil at seeding time it was expected that the treatment III exchangeable phosphorus values determined for each crop would be approximately 36 mgm. larger than the corresponding treatment I values. This was not the case. In general, the treatment III values were only slightly larger than the corresponding treatment I values. The treatment III values are approximately equal for all crops. The treatment I values for flax and oats are similar and are lower than that for rapeseed. Considering that the treatment III exchangeable phosphorus values are the same for all crops it would appear that the very large treatment I exchangeable phosphorus value for rapeseed must be incorrect due to some experimental error.

Summary and Conclusions

The phosphorus feeding habits of flax, oats and rapeseed were studied using P32 tracer to determine "A" values and exchangeable phosphorus values for a high-lime soil. The crops were grown in the greenhouse for a period of about seven weeks, after which time they were harvested, dried, weighed and analyzed to determine their contents of phosphorus and tracer P32.

Flax used very small amounts of both soil and fertilizer

phosphorus. In contrast, oats and rapeseed used relatively large quantities. When exposed to conditions of phosphorus stress oats was able to obtain nearly two times as much soil phosphorus as was rapeseed. These data offer the most conclusive evidence that oats is a stronger soil phosphorus feeder than is rapeseed.

The magnitude of the response of phosphate fertilizer decreased in the order rapeseed, oats, flax. Additions of phosphate fertilizer nearly doubled the yield of rapeseed plant material. The yield of oat plant material was increased by approximately one-third. Flax showed a slight response to phosphate fertilizer mixed throughout the soil but no response to the phosphate band application.

The per cent utilization of fertilizer phosphorus decreased in the order rapeseed, oats, flax, for all fertilized treatments. Rapeseed made very efficient use of phosphorus applied as a fertilizer band, much more so than did oats. The per cent utilization of banded phosphorus by oats was decreased one-fourth when 20 ppm of phosphorus was mixed throughout the soil. The same fertilizer treatment decreased the per cent utilization of banded phosphorus by rapeseed only one eighth. These data indicate that rapeseed prefers to obtain phosphorus from the band area in which the concentration of available phosphate is high relative to the rest of the soil. Oats and flax do not show the same preference.

Treatments II and IV "A" values determined with the three crops decreased in the order flax, oats, rapeseed, indicating that the soil phosphorus was most available to flax, less available to oats, and

least available to rapeseed.

Treatment III "A" value data indicated that flax is a stronger soil phosphorus feeder than are oats or rapeseed.

On the basis of the experimental data presented it was concluded that the phosphorus feeding habits of flax, oats and rapeseed are different. Rapeseed makes very efficient use, oats makes less efficient use, and flax makes practically no use of fertilizer phosphorus. Rapeseed shows the largest response, oats responds to a lesser degree than does rapeseed, and flax shows very little response to fertilizer phosphorus. Rapeseed shows a greater preference than does oats or flax for phosphorus from the fertilizer band. Soil phosphorus is most available to flax, less available to oats and least available to rapeseed.

Since the amount of flax plant material produced in the seven week period was much smaller than that produced by oats or rapeseed it was felt that the direct comparison of the flax, oat and rapeseed data might leave cause for concern. It was assumed that a more valid comparison of data could be made if the quantities of plant material produced were nearly equal. It was concluded that further greenhouse experiments of a similar nature having larger flax plant populations in each pot would have to be conducted before any really concrete conclusions could be made concerning the phosphorus feeding habits of flax, oats and rapeseed.

GREENHOUSE EXPERIMENT II

Methods and Materials

Greenhouse experiment II was conducted to study the phosphorus feeding habits of flax, oats and rapeseed, and to investigate how and to what extent yield of plant material affected the "A" value determined with flax. In effect, the purpose of the study was to determine whether a valid comparison of flax, oat and rapeseed "A" values could be made if the plant material yields of the crops were unequal.

An experiment similar to greenhouse experiment I was designed to contain four replicates of one fertilizer treatment. It was planned that "A" values would be determined for the Balmoral soil (26) using populations of 10, 20, 30 and 40 flax plants and four oat and rapeseed plants. The soil was prepared in the same manner as that described for experiment I and 1800 gm. portions of air dry soil were weighed into twenty-four, one-half gallon glazed porcelain pots. At seeding time 10 ml. of an activated KH_2PO_4 solution containing .018 gm. of phosphorus and 9 μc of P^{32} was banded one and one-half inches below the soil surface in each pot.

The crops were seeded February 23, 1963 and the plant materials produced were harvested eight weeks later, April 22. The procedures followed in seeding, caring for and harvesting the crops are discussed under methods and materials, experiment I.

Results and Discussion

The flax plant populations were not as large as those anticipated due to poor seed germination. They ranged from seven plants to twenty-seven plants. To avoid confusion the size of population is listed with the corresponding data in each table.

The yields of plant material in gms. of oven dry weight and the per cent phosphorus data are listed in Table XIX.

Yields of plant material

The yields of flax plant material ranged from 2.95 gms. for the seven plant population to 5.00 gms. for the twenty-three plant population. The yields of oat and rapeseed plant materials were somewhat greater than those of the largest flax populations. The average yields of oat and rapeseed plant materials were 7.70 and 6.35 gms. respectively.

Per cent phosphorus in the plant material

The experiment I data showed that the phosphorus content of flax plant material grown for a six week period was greater than that of oats or rapeseed grown for the same period of time. Experiment II data show that the phosphorus content of plant materials grown for an eight week period is greatest for oats, less for rapeseed and least for flax.

Phosphorus Utilization Data

The phosphorus utilization data for flax, oats and rapeseed

TABLE XIX

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PLANT POPULATION, YIELDS OF OVEN DRY MATERIAL AND THE PER CENT PHOSPHORUS
IN THE PLANT MATERIALS

Crop	Population	Wt. of oven-dry plant matter (gms.)	Total P. in plant matter as a % of plant weight
Flax	7	2.95	.19
	10	3.40	.17
	10	3.50	.18
	11	3.50	.17
	14	4.25	.17
	15	4.25	.16
	16	4.40	.17
	17	4.30	.17
	17	3.75	.17
	19	4.20	.15
	19	4.35	.17
	20	4.65	.19
	20	4.70	.17
	20	4.75	.16
	23	5.00	.16
27	4.75	.21	
Oats	4	7.70	.24
Rapeseed	4	6.35	.20

including total phosphorus uptake in mgm., uptake of soil phosphorus in mgm., uptake of fertilizer phosphorus in mgm., per cent utilization of fertilizer phosphorus and "A" value data are listed in Table XX.

Total phosphorus uptake

The total quantities of phosphorus used by flax varied from 5.66 mgm. for the seven plant population to 10.12 mgm. for the twenty-seven plant population. The four plant populations of oats and rapeseed both used larger amounts of phosphorus than did the twenty-seven plant population of flax. Oats took up one and one-half times as much phosphorus as did rapeseed and about two times as much phosphorus as did many of the larger populations of flax plants.

Uptake of soil phosphorus

The quantities of soil phosphorus taken up by flax ranged from 4.50 mgm. to 8.05 mgm. Rapeseed took up 7.10 mgm. soil phosphorus, a quantity approximately equalling that used by the larger flax populations. Oats used nearly two times as much soil phosphorus as did rapeseed and flax.

Uptake fertilizer phosphorus in mgm.

The quantities of fertilizer phosphorus taken up by flax ranged from 1.16 mgm. to 2.60 mgm., small amounts as compared to those for oats and rapeseed. Oats and rapeseed took up 4.58 and 5.66 mgm. of fertilizer phosphorus respectively. On the average, one-fifth of the phosphorus in the flax plant material was derived from the

TABLE XX

PHOSPHORUS UTILIZATION DATA AND "A" VALUES

Crop	Population	Total mgm. P. taken up	Uptake soil P. mgm.	Uptake fertilizer P. mgm.	% utilization fertilizer P.	"A" value mgm. P.	Average flax "A" value mgm. P.
Flax	7	5.66	4.50	1.16	6.42	69.8	60.7
	10	5.92	4.67	1.25	6.94	67.3	
	10	6.41	4.78	1.63	9.05	52.7	
	11	6.09	4.66	1.43	7.97	58.7	
	14	7.40	5.88	1.52	8.46	69.7	
	15	6.89	5.16	1.73	9.59	53.6	
	16	7.39	5.98	1.41	7.83	76.3	
	17	7.48	5.28	2.20	12.23	43.2	
	17	6.30	4.87	1.43	7.95	61.4	
	19	6.43	5.01	1.42	7.88	63.5	
	19	7.57	5.82	1.75	9.70	59.9	
	20	8.93	6.33	2.60	14.45	43.7	
	20	8.18	5.63	2.55	14.15	39.8	
	20	7.80	6.09	1.71	9.50	64.1	
	23	8.10	6.57	1.53	8.48	77.2	
	27	10.12	8.05	2.07	11.52	70.0	
Oats	4	18.36	13.78	4.58	25.43	54.4	
Rapeseed	4	12.76	7.10	5.66	31.42	22.6	

fertilizer. In contrast, one-third of the phosphorus in the oats and slightly less than one-half of the phosphorus in the rapeseed plant materials was derived from the fertilizer. It is significant to note that although the total quantity of phosphorus in the oat plant material was one and one-half times that in the rapeseed plant material, rapeseed used approximately one-fourth more fertilizer phosphorus than did oats. The twenty-seven plant population of flax took up nearly as large a total quantity of phosphorus as did rapeseed but it took up only about one-third as much fertilizer phosphorus as did rapeseed.

Per cent utilization of fertilizer phosphorus

Although the experiment II crops, grown eight weeks, used larger proportions of the added fertilizer phosphorus than did the corresponding experiment I crops grown six weeks, the same trends are evident in both sets of data. Rapeseed took up a larger proportion of the fertilizer phosphorus added than did oats and oats took up a larger proportion than did flax.

The per cent utilization of fertilizer phosphorus data for experiment II show that the different populations of flax took up between 6.42 and 14.45 per cent of the fertilizer phosphorus. The data show that flax is not a highly efficient user of banded fertilizer phosphorus, but if required to do so, it is able to use appreciable quantities of phosphorus added in this manner. Oats took up one-quarter of the fertilizer phosphorus added. Rapeseed was the most efficient user of fertilizer phosphorus, taking up nearly one-third of that added.

"A" values

The experiment II "A" values were larger than the corresponding treatment II, experiment I "A" values because the crops were grown for a longer period of time in the second experiment than in the first. The experiment I "A" values for flax, oats and rapeseed were 48.0 mgm., 34.2 mgm. and 13.8 mgm. of elemental phosphorus respectively. The corresponding experiment II values were 60.7 mgm., 54.4 mgm. and 22.6 mgm. of elemental phosphorus. Both sets of "A" values decreased in the order flax, oats, rapeseed, indicating that native phosphorus in the Balmoral soil was most available to flax, less available to oats and least available to rapeseed.

The three flax plant populations grown in experiment I produced approximately one-fourth as much plant material as did oats or rapeseed. The average flax "A" value was appreciably larger than that determined with oats and more than three times as large as that determined with rapeseed. The yields of plant material produced by flax, oats and rapeseed grown in experiment II were larger and were more nearly equal for all crops than was the case in the previous investigation. Experiment II "A" value data indicated that increasing the yield of plant material produced a proportionally larger increase in the oat "A" value than in the flax or rapeseed "A" values. The flax "A" value was only slightly larger than that determined with oats. Both the flax and oat "A" values were approximately three times as large as that determined with rapeseed. Thus, even though the experiment II flax plants were larger and took up much larger quantities

of fertilizer phosphorus than those grown in experiment I the "A" value determined with flax was approximately three times that determined with rapeseed. The same observation was noted in the discussion of experiment I data.

The flax data show that although the "A" values determined with the different plant populations are variable there is no correlation between the size of plant population and the size of "A" value determined (e.g. the "A" values determined for the seven and twenty-seven plant populations are equal).

Summary and Conclusions

A greenhouse experiment employing radioactive tracer P32 was designed to study the phosphorus feeding habits of flax, oats and rapeseed and to determine whether the size of flax plant material yield affected the magnitude of the "A" value determined for that crop.

The phosphorus utilization data for the three crops grown on a high-lime soil show that four oat plants used a larger total quantity of phosphorus than did four rapeseed plants or twenty-seven flax plants. Oats took up a larger quantity of soil phosphorus than did flax or rapeseed. Many of the larger flax plant populations took up quantities of soil phosphorus nearly equal to that taken up by rapeseed. Rapeseed used a larger quantity of fertilizer phosphorus than did either oats or flax. Rapeseed derived just less than one-half of its total phosphorus from the fertilizer band. Oats and flax derived one-third and one-fifth, respectively, of their total phosphorus from

the fertilizer band. Rapeseed used one-third, oats used one-fourth and flax used about one-tenth of the fertilizer phosphorus added.

"A" values determined for the three crops decreased in the order flax, oats and rapeseed. The "A" values determined with flax were variable and showed no correlation with the size of the flax plant population.

On the basis of phosphorus utilization data derived from experiments I and II it was concluded that there are real differences in the phosphorus feeding habits of flax, oats and rapeseed. When grown on a high-lime soil rapeseed shows a greater preference for phosphorus from the fertilizer band than does oats. Oats makes relatively efficient use of fertilizer phosphorus but at the same time uses large quantities of native soil phosphorus. Flax shows a preference for soil phosphorus and uses only relatively small quantities of fertilizer phosphorus as compared to that used by the other two crops.

On the basis of flax "A" value data determined in experiment II it was concluded that a direct comparison of flax "A" values with oat and rapeseed "A" values could be made despite large differences in the corresponding yields of plant material.

On the basis of "A" value data for the three crops it was concluded that soil phosphorus in the Balmoral soil was most available to flax, slightly less available to oats and least available to rapeseed. Rapeseed, it would appear, has a greater ability than has oats or flax to obtain large quantities of phosphorus from an area of high

phosphate concentration (e.g. the phosphate fertilizer band).

The field and greenhouse data provide definite evidence that the phosphorus feeding habits of flax, oats and rapeseed differ in many respects. That the crops differ in their total phosphorus requirements for growth to maturity, in the stage(s) of growth at which phosphorus is taken up, and in their rates of phosphate uptake during these stage(s) was readily understandable because, as was pointed out by the field data, the growth habits of the three crops differ widely. That the ratio of phosphorus taken from the soil to phosphorus taken from the fertilizer band was different in each of the three crops was not so readily understandable. Hypothesis postulated to account for these differences were:

1. Flax, oats and rapeseed differ in their abilities to obtain phosphorus from very dilute phosphate solutions (i.e. the soil solution).
2. Flax, oats and rapeseed may specifically affect the availability of soil phosphorus (i.e. the crops may differ with respect to their soil phosphorus feeding powers).
3. The pH of the fertilizer band may be more conducive to the growth and development in the band area of rapeseed and oat roots than to flax roots.

In an attempt to elucidate the differences in the ratios of soil phosphorus to fertilizer phosphorus in the three plant materials several short term experiments were conducted.

GREENHOUSE EXPERIMENT III

Methods and Materials

A nutrient solution experiment was designed to investigate phosphorus uptake by flax, oats and rapeseed from nutrient media containing widely different concentrations of phosphorus. Radioactive tracer P32 was employed to measure the quantities of phosphorus removed from the solutions. Four harvests of five treatments were grown for each of the crops. The treatments were not replicated.

The five treatments to which each crop was subjected were nutrient media containing 30.0 ppm, 3.0 ppm, 1.0 ppm, 0.3 ppm and 0.03 ppm of elemental phosphorus. Harvests of the plant materials were taken at periods of 24 hours, 48 hours, 96 hours and 168 hours after addition of the nutrient media of P32.

The experiment required that seedling plants be used for test purposes. The seeds were germinated and the plants were grown in crushed brick sold commercially under the trade name "Turface". Crushed brick rather than sand or soil was chosen for this purpose because it holds water much better than does sand and is more easily removed from plant roots than is soil. The seeds were planted May 30. The seedling plants were watered every third day with a complete nutrient medium to promote rapid growth. The nutrient medium preparation is described by Machlis and Torrey (20). The three crops were subjected to the experimental conditions at different times so that at no time were there more than twenty bottles of plants being

tested. Oats was transferred to the test media June 4. Rapeseed and flax were transferred to the test media June 28 and July 10 respectively. Harvests Ia and IIa oat plants were transferred to the test media July 16.

One hundred and eighty ml. portions of the test media were added to 8 fluid oz. glass jars. The sides of the jars were covered with aluminum foil to decrease the amount of light entering the nutrient solutions and the mouths of the jars were covered with polyethylene in which a number of small holes had been punched. Three plants were placed in each jar. To ensure that just the roots of the oat plants were bathed in the nutrient solution, oats were supported in the polyethylene cover by placing small wads of pyrex wool in the hole around the stem. The lower leaves of flax and rapeseed supported those plants so that no wadding was required. Wire supports were used to maintain the plants in each bottle in an upright position. Air was constantly bubbled through the media in the bottles to maintain a condition of aerobiosis in which root development and active nutrient uptake could take place.

To maintain the concentrations of phosphorus in the nutrient media as nearly constant as possible the media were changed every 24 hours. A rubber syringe connected to two lengths of rubber tube was employed to pump the used media from the bottles. Fresh media were added to the bottles using long stemmed glass funnels.

All plants were placed in the test media for a period of approximately five days before P32 was added. This adjustment period

allowed time for the plants to recover from the shock of being transplanted and let them become accustomed to the new environmental conditions to which they had been subjected. It was assumed that the plants were actively growing and taking up phosphorus when P32 was added to the nutrient media.

One millicurie of carrier free P32 was obtained June 18, 1963 and was diluted to one litre (i.e. 1 ml. of the solution prepared originally contained 1 uc P32). Before use the solution was stored overnight in a teflon container so that all of the adsorption sites on the container walls might become saturated with P32. On June 19 1 ml. of the carrier free P32 solution was added to the 180 ml. of nutrient medium in each of the jars in which oats was growing. P32 was first added to the nutrient media in which rapeseed and flax were growing on July 3 and July 15 respectively. The harvests Ia and IIa oats received P32 on July 18. Each day the used nutrient media were replaced with fresh nutrient media. As a result it was necessary to add 1 ml. of the P32 solution to each of the new media each day. (e.g. the plants under test for the 168 hour period had access to 7 ml. of P32 solution). The P32 solution remaining after all crops had been tested was stored to be used as a counting standard against which the plant material counts might be compared.

After the experiment had been conducted using oats and rapeseed and some of the data had been calculated, it was decided that a good test of the experimental technique would be to try to account for all of the P32 added to the nutrient media. With this idea in

mind the used nutrient media and the root washings from harvests I and II of flax and from harvests Ia and IIa of oats were saved and were counted.

One group of three plants from each of the five treatments was harvested at each harvest date. The plants were taken from the nutrient media and their roots were washed for approximately five seconds in a stream of distilled water to ensure complete removal of nutrient solution containing P31 and P32 which had adhered to the roots. The washed roots were pressed between paper towels to remove the surface moisture. After recording their fresh weights, the plant materials were placed in an oven and were dried at 90° C. for 12 hours. The oven dry weights of plant material were recorded.

The entire oat and flax plant materials were wet ashed. The large yields of rapeseed made grinding necessary in order to obtain representative one gram samples of rapeseed plant materials to be wet ashed. Aliquots of the ash solutions were taken for total phosphorus analyses and radioactive counting.

Results and Discussion

Tables XXI, XXII and XXIII list the yields of plant material in gms. of fresh weight, the per cent moisture in the plant materials and the concentration of phosphorus in the plant solution in mgm. per ml. assuming that the total phosphorus in the plant materials existed in solution for flax, oats and rapeseed respectively.

TABLE XXI

THE YIELDS OF FRESH FLAX PLANT MATERIAL, THE PER CENT MOISTURE IN THE PLANT MATERIALS AND THE CONCENTRATIONS OF PHOSPHORUS IN THE PLANT SOLUTIONS

Harvest	Phosphorus conc'n.	Fresh wt. of plant matter	% moisture in fresh plant matter	Conc'n. of phosphorus in plant sol'n mgm./ml.
I	0.03	1.07	77.5	.330
	0.3	.78	75.6	.675
	1.0	1.01	80.2	.768
	3.0	1.07	81.3	.829
	30.0	2.07	84.5	1.308
II	0.03	1.16	81.0	.344
	0.3	1.75	82.9	.463
	1.0	1.57	82.2	.695
	3.0	1.33	83.5	.807
	30.0	1.47	82.3	1.049
III	0.03	2.16	81.9	.407
	0.3	1.81	84.0	.524
	1.0	1.12	82.0	.784
	3.0	2.61	85.4	.904
	30.0	3.50	86.3	1.301
IV	0.03	1.81	82.3	.334
	0.3	1.41	79.4	.488
	1.0	2.06	81.1	.834
	3.0	3.62	82.3	1.219
	30.0	2.18	84.9	1.371

TABLE XXII

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THE YIELDS OF FRESH OAT PLANT MATERIAL, THE PER CENT MOISTURE IN THE PLANT MATERIALS AND THE CONCENTRATIONS OF PHOSPHORUS IN THE PLANT SOLUTIONS

Harvest	Phosphorus conc'n.	Fresh wt. of plant matter	% moisture in fresh plant matter	Conc'n. of phosphorus in plant sol'n mgm./ml.
I	0.03	2.65	88.3	.213
	0.3	3.55	89.6	.244
	1.0	3.05	89.8	.443
	3.0	3.85	89.1	.834
	30.0	2.80	88.6	1.642
II	0.03	3.30	87.3	.173
	0.3	3.80	88.7	.295
	1.0	3.80	88.4	.381
	3.0	4.25	88.5	.827
	30.0	3.5	88.3	1.620
III	0.03	3.5	86.0	.165
	0.3	4.35	88.0	.219
	1.0	5.60	88.8	.350
	3.0	6.32	89.4	.672
	30.0	6.12	89.1	1.483
IV	0.03	5.37	89.3	.097
	0.3	6.31	88.0	.179
	1.0	10.00	90.0	.262
	3.0	13.70	90.5	.404
	30.0	13.14	89.8	2.150
Ia	0.03	4.62	89.4	.535
	0.3	4.43	89.2	.594
	1.0	5.55	91.0	.616
	3.0	5.15	88.9	.774
	30.0	4.92	89.2	1.013
IIa	0.03	4.95	89.5	.498
	0.3	4.49	89.1	.513
	1.0	4.44	89.0	.661
	3.0	5.14	89.1	.808
	30.0	4.92	89.4	1.053

TABLE XXIII

THE YIELDS OF FRESH RAPESEED PLANT MATERIAL, THE PER CENT MOISTURE IN THE PLANT MATERIALS AND THE CONCENTRATIONS OF PHOSPHORUS IN THE PLANT SOLUTIONS

Harvest	Phosphorus conc'n.	Fresh wt. of plant matter	% moisture in fresh plant matter	Conc'n of phosphorus in plant sol'n mgm./ml.
I	0.03	19.64	89.1	.274
	0.3	23.29	89.1	.275
	1.0	27.07	88.7	.366
	3.0	23.18	89.3	.417
	30.0	31.30	92.8	.960
II	0.03	19.90	88.5	.315
	0.3	24.92	88.8	.303
	1.0	26.64	88.9	.265
	3.0	20.57	89.9	.392
	30.0	23.02	89.9	1.288
III	0.03	24.39	87.2	.201
	0.3	28.30	87.6	.194
	1.0	23.01	88.1	.243
	3.0	33.16	89.0	.276
	30.0	39.53	91.2	.897
IV	0.03	32.14	85.8	.186
	0.3	33.43	86.6	.193
	1.0	32.51	85.7	.260
	3.0	56.22	87.9	.249
	30.0	67.88	90.2	.860

Yields of fresh plant material

The yields of fresh rapeseed plant material were much larger than those of oats and flax. As was stated in the methods and materials sections, the rapeseed plants were grown in "Turface" and were given the complete nutrient medium for a three week longer period than were oats, before being subjected to experimental conditions. Rapeseed grew rapidly during this period and was much larger when subjected to experimental conditions than was oats. Although flax received the complete nutrient medium for a longer period of time than did rapeseed it grew very slowly and the resulting yields of fresh flax plant material were small.

The yield of fresh rapeseed plant material nearly doubled in the 0.03, 0.3 and 1.0 ppm of phosphorus nutrient media and more than doubled in the 3.0 and 30.0 ppm of phosphorus media during the seven day period on which the experiment was conducted. The yields of fresh oat plant material approximately doubled in the 0.03 and 0.3 ppm of phosphorus media and approximately quadrupled in the 3.0 and 30.0 ppm of phosphorus media during the same period. Flax grew very little during the seven day experimental period.

Per cent moisture in the plant materials

The moisture contents of oat and rapeseed plant materials were approximately equal. The moisture content of flax plant material was somewhat less than that for the other two crops. The different phosphorus concentrations in the experimental nutrient media caused

no consistent differences in the moisture contents of the plant materials.

Concentrations of phosphorus in the plant solutions

The concentrations of phosphorus in all plant solutions increased with increasing concentration in the experimental nutrient media to which the plants had been subjected. The concentrations of phosphorus in the flax plant solutions remained approximately constant throughout the seven day experimental period while those in the rapeseed plant solutions decreased slightly during the same period. The concentrations of phosphorus in the plant solution of oats grown in the 0.03, 0.3, 1.0 and 3.0 ppm of phosphorus nutrient media decreased and in the 30.0 ppm of phosphorus nutrient medium increased during the experimental period. These data suggest that the supply of phosphorus in the low phosphate concentration nutrient media was a factor limiting plant growth. In contrast, flax, oats and rapeseed in the 30.0 ppm of phosphorus nutrient medium and flax grown in the 3.0 ppm of phosphorus nutrient medium consumed luxury quantities of phosphorus.

The harvests Ia and IIa oat data differ somewhat from the other oat data because the harvests Ia and IIa plants were slightly larger when subjected to experimental conditions than were the other plants and they remained in the nutrient media only two days before P₃₂ was added. The resulting concentrations of phosphorus in the plant solutions were more nearly equivalent than was true of the previously discussed oat data, however, the data for plants subjected to the

30.0 ppm of phosphorus nutrient medium show signs of luxury phosphorus consumption.

Tables XXIV, XXV and XXVI list the yields in gms. of oven dry plant material, the per cent phosphorus in the plant materials and the phosphorus utilization data for flax, oats and rapeseed respectively.

Yields of oven dry plant material

The trends in the yields of oven dry plant material data correspond very closely to those discussed under the heading "Yields of fresh plant material". Rapeseed produced the largest quantity of oven dry plant material and flax produced the least. The yields of rapeseed plant material approximately doubled during the seven day experimental period. The yields of oats grown in the 0.03 and 0.3 ppm of phosphorus media doubled and those of oats grown in the 3.0 and 30.0 ppm of phosphorus solutions approximately quadrupled in the same period. The yields of flax were variable, however, on the average they showed some increase with time.

Rapeseed and oats showed definite increases in plant growth with increasing phosphorus concentration in the nutrient media. Flax data indicated the same general trend although it was not as well defined for flax as for the other two crops. At harvests III and IV rapeseed and oats grown in the 3.0 ppm of phosphorus nutrient medium had produced yields of plant material equal to or slightly larger than the yields of the corresponding crops grown in the 30.0 ppm of phosphorus medium. These data indicated that rapeseed and oats

TABLE XXIV

THE YIELDS OF OVEN DRY PLANT MATERIAL, THE PER CENT PHOSPHORUS IN THE PLANT MATERIALS AND THE
PHOSPHORUS UTILIZATION DATA FOR FLAX

Harvest	Phosphorus conc'n.	Wt. of oven dry plant matter	Total P. mgm.	% P. in plant matter	% uptake of sol'n P.	Uptake sol'n P. mgm.
I	0.03	.24	.274	.11	32.8	.002
	0.3	.19	.398	.21	48.1	.026
	1.0	.20	.622	.31	34.4	.062
	3.0	.20	.721	.36	16.2	.088
	30.0	.32	2.289	.72	15.4	.832
II	0.03	.22	.323	.15	48.1	.005
	0.3	.30	.672	.22	66.1	.071
	1.0	.28	.896	.32	55.8	.200
	3.0	.22	.896	.41	23.1	.250
	30.0	.26	1.269	.49	9.0	.972
III	0.03	.39	.721	.19	46.4	.010
	0.3	.29	.796	.27	53.8	.116
	1.0	.20	.721	.36	41.3	.297
	3.0	.38	2.015	.53	41.2	.890
	30.0	.48	3.930	.82	15.6	3.370
IV	0.03	.32	.498	.16	31.7	.012
	0.3	.29	.547	.19	52.9	.200
	1.0	.39	1.393	.36	57.9	.730
	3.0	.64	3.632	.57	45.5	1.720
	30.0	.33	2.537	.77	6.25	2.363

TABLE XXV

THE YIELDS OF OVEN DRY PLANT MATERIAL, THE PER CENT PHOSPHORUS IN THE PLANT MATERIAL AND THE
PHOSPHORUS UTILIZATION DATA FOR OATS

Harvest	Phosphorus conc'n.	Wt. of oven dry plant matter	Total P. mgm.	% P. in plant matter	% uptake of sol'n P.	Uptake sol'n P. mgm.
I	0.03	.31	.498	.16	34.5	.002
	0.3	.37	.777	.21	72.2	.039
	1.0	.31	1.213	.39	73.1	.132
	3.0	.42	2.861	.68	75.4	.407
	30.0	.32	4.073	1.27	14.4	.780
II	0.03	.42	.498	.12	33.0	.004
	0.3	.43	.995	.23	82.5	.089
	1.0	.44	1.279	.29	88.9	.320
	3.0	.49	3.110	.63	80.1	.865
	30.0	.41	5.006	1.22	14.9	1.608
III	0.03	.49	.498	.10	41.6	.009
	0.3	.52	.840	.16	80.8	.175
	1.0	.63	1.741	.28	92.0	.662
	3.0	.67	3.794	.57	92.6	2.000
	30.0	.67	8.085	1.21	24.8	5.361
IV	0.03	.57	.467	.08	39.0	.015
	0.3	.76	.995	.13	79.3	.300
	1.0	1.00	2.363	.24	85.8	1.082
	3.0	1.30	5.006	.39	84.5	3.200
	30.0	1.34	25.374	1.89	51.9	19.618
Ia	0.03	.49	2.208	.45	82.3	.004
	0.3	.48	2.347	.49	79.4	.043
	1.0	.50	3.110	.62	87.8	.158
	3.0	.57	3.545	.62	64.6	.349
	30.0	.53	4.447	.84	20.1	1.085

TABLE XXV (continued)

Harvest	Phosphorus conc'n.	Wt. of oven dry plant matter	Total P. mgm.	% P. in plant matter	% uptake of sol'n P.	Uptake sol'n P. mgm.
IIa	0.03	.52	2.208	.42	71.7	.008
	0.3	.49	2.052	.42	81.3	.088
	1.0	.49	2.612	.53	80.0	.288
	3.0	.56	3.700	.66	68.9	.744
	30.0	.52	4.633	.89	19.5	2.106

THE YIELDS OF OVEN DRY PLANT MATERIAL, THE PER CENT PHOSPHORUS IN THE PLANT MATERIALS AND THE
PHOSPHORUS UTILIZATION DATA FOR RAPESEED

Harvest	Phosphorus conc'n.	Wt. of oven dry plant matter	Total P. mgm.	% P. in plant matter	% uptake of sol'n P.	Uptake sol'n P. mgm.
I	0.03	2.14	4.791	.22	77.25	.004
	0.3	2.55	5.709	.22	71.2	.038
	1.0	3.07	8.783	.29	72.7	.131
	3.0	2.48	8.637	.35	77.7	.420
	30.0	3.27	27.861	.85	69.25	3.740
II	0.03	2.29	5.554	.24	72.6	.008
	0.3	2.97	6.650	.22	74.9	.081
	1.0	2.97	6.280	.21	77.6	.279
	3.0	2.08	7.244	.35	79.7	.860
	30.0	2.33	26.662	1.14	71.5	7.723
III	0.03	3.12	4.269	.14	77.2	.017
	0.3	3.51	4.802	.14	77.6	.168
	1.0	2.73	4.924	.18	77.7	.559
	3.0	3.64	8.150	.22	80.5	1.740
	30.0	3.49	32.340	.93	70.3	15.185
IV	0.03	4.57	5.116	.11	58.6	.022
	0.3	4.49	5.585	.12	65.9	.249
	1.0	4.65	7.230	.16	68.9	.868
	3.0	6.83	12.318	.18	79.0	2.987
	30.0	6.62	52.700	.80	69.5	26.260

were able to obtain sufficient phosphorus from the 3.0 ppm of phosphorus medium to support optimum growth and suggested that consumption of luxury quantities of phosphorus from the 30.0 ppm of phosphorus medium, if anything, somewhat reduced plant growth.

Phosphorus Utilization Data

Per cent phosphorus in the plant materials

The per cent phosphorus data, although not identical for the three, were similar and showed the same general trends for all crops. There was a general increase in the phosphorus contents of all plant materials from the plants grown in the 0.03 ppm of phosphorus nutrient medium to those grown in the 30.0 ppm of phosphorus nutrient medium. The phosphorus contents of plant materials grown in the medium of least phosphorus concentration were initially very low and decreased during the experiment, while those in the medium of highest phosphorus concentration were initially very high and increased, or in the case of rapeseed, remained approximately constant during the experiment.

The yields of plant material suggested that the crops grew best in the 3.0 ppm of phosphorus nutrient medium. This being the case the percentages of phosphorus in the plant materials grown in that medium were approximately those required for optimum growth. The per cent phosphorus data again show that plants grown in the 0.03, 0.3 and the 1.0 ppm of phosphorus media were unable to obtain enough phosphorus for optimum growth and that plants grown in the 30.0 ppm of

phosphorus medium consumed luxury quantities of phosphorus. For example, oats at harvest IV contained 1.89 per cent phosphorus.

Total phosphorus in the plant materials

The total quantities of phosphorus in the rapeseed plant materials were larger than those in the corresponding oat and flax plant materials at each harvest. Flax plants produced the least plant material and contained the least total phosphorus of the three crops studied. The total phosphorus data showed that the quantity of phosphorus in all plant materials at each harvest increased with increasing concentration of phosphorus in the nutrient media. This trend is less well defined for flax than for oats and rapeseed because the flax plants were relatively small and at no time during the experiment showed a capacity to use the very large quantities of phosphorus used by oats and rapeseed.

The total phosphorus data indicated that during the seven day experimental period oats and rapeseed took up approximately 22.0 mgm. and 28.0 mgm. respectively of phosphorus from the 30.0 ppm of phosphorus nutrient medium. The same crops took approximately 2.6 mgm. and 4.0 mgm. respectively of phosphorus from the 3.0 ppm of phosphorus nutrient medium in which both crops produced slightly larger yields of plant material than were produced in the medium of higher phosphate concentration. These data showed that rapeseed and oats have surprisingly large capacities to consume luxury quantities of phosphorus. Flax did not appear to have the same capacity to take

up and store phosphorus. The data indicate that flax just took up the quantity of phosphorus it required for growth.

At harvest I oats, and in particular rapeseed, grown in the 30.0 ppm of phosphorus medium contained much larger quantities of phosphorus than did the same crops grown in the 3.0 ppm of phosphorus medium. The large initial differences in the phosphorus contents of the plants grown in the two media resulted because they were subjected to experimental conditions several days before P32 was first added. For example, rapeseed remained in the nutrient media seven days before P32 was added. If the plants in the 30.0 ppm of phosphorus medium took up 3.7 mgm. of phosphorus per day the total quantity of phosphorus taken up in seven days would have been $7 \times 3.7 = 25.9$ mgm. During the same seven days rapeseed probably obtained about 2.8 mgm. of phosphorus from the 3.0 ppm of phosphorus medium.

Per cent utilization of phosphorus supplied in the nutrient media

The phosphorus utilization data indicate that throughout the experiment rapeseed took up an approximately constant proportion (75 per cent) of the phosphorus supplied in all nutrient media. Oats took up a larger proportion of the phosphorus supplied in the 0.3, 1.0 and 3.0 ppm of phosphorus solutions than did rapeseed. Initially oats was unable to use as much phosphorus as could rapeseed and as a result the proportion of the total phosphorus taken from the 30.0 ppm of phosphorus medium by oats was small. As the experiment progressed oats grew and its capacity to take up phosphorus vastly

increased. Harvests I, II, III and IV oat data suggested that oats experienced difficulty in obtaining phosphorus from the 0.03 ppm of phosphorus medium. Harvests Ia and IIa data showed that oat plants in a healthy condition could obtain phosphorus from that medium as readily as could rapeseed. The phosphorus utilization data show that flax took up variable proportions of the total phosphorus supplied in the nutrient media and that it took up no more than two-thirds of the phosphorus supplied in any of the media.

Initially it was assumed that unless the crops differed in their abilities to take phosphorus from dilute phosphate solutions all crops would utilize all of the phosphorus supplied in the 0.03, 0.3, 1.0 and 3.0 ppm of phosphorus media. When it was observed that oats removed no more than 93 per cent and rapeseed removed no more than 80 per cent of the phosphorus from these media it was suggested that microorganisms were growing in the carrier free P32 solution and were incorporating the P32 into their bodies making it unavailable to plants, or that the P32 added to the media was in some way fixed making it unavailable to plants.

Table XXVII lists the proportion of added P32 in the plant matter, the proportion of added P32 remaining in the nutrient medium after the test period and the total proportion of the added P32 accounted for, for harvests I and II of flax and harvests Ia and IIa of oats.

Harvests Ia and IIa oats took up as much as 88 per cent of the P32 added to the nutrient media. Since these oats were subjected to

TABLE XXVII
 THE QUANTITIES OF TRACER P32 ACCOUNTED FOR WHEN FLAX AND OATS WERE
 GROWN IN THE NUTRIENT MEDIA

Crop	Harvest	Phosphorus conc'n.	% of P32 added in plant matter	% of P32 added in solution	% of P32 added accounted for
Flax	I	0.03	32.8	42.8	75.6
		0.3	48.1	33.0	81.1
		1.0	34.4	49.4	83.8
		3.0	16.2	75.6	91.8
		30.0	15.4	80.5	95.9
	II	0.03	48.1	23.2	71.3
		0.3	66.1	8.1	74.2
		1.0	55.8	25.5	81.3
		3.0	23.1	67.9	91.0
		30.0	9.0	84.0	93.0
Oats	Ia	0.03	82.3	14.4	96.7
		0.3	79.4	6.7	86.1
		1.0	87.8	4.2	92.0
		3.0	64.6	24.3	88.9
		30.0	20.1	76.1	96.2
	IIa	0.03	71.7	11.3	83.0
		0.3	81.3	6.0	87.3
		1.0	80.0	7.1	87.1
		3.0	68.9	17.9	86.8
		30.0	19.5	74.9	94.4

experimental conditions after all other tests had been completed these data indicate that nearly all of the P32 added to the nutrient media was available to all crops. When the P32 remaining in the nutrient media was taken into consideration 75 to 97 per cent of that added could be accounted for. These data suggest that although a very small amount of P32 added to the nutrient media may have been made unavailable to plants by adsorption or loss of solution, certainly more than 90 per cent was available for plant use.

Experimental evidence thus indicates that the phosphorus utilization data are true measures of the amounts of phosphorus the crops could obtain from the nutrient media. All crops were able to take phosphorus from the very dilute 0.03 ppm of phosphorus medium. Oats took up 85 to 90 per cent, rapeseed took up 77 per cent and flax took up approximately 50 per cent of the phosphorus from the 0.03, 0.3, 1.0 and 3.0 ppm of phosphorus media. The utilization of phosphorus supplied in the 30 ppm of phosphorus solution varied with the abilities of the crops to take up excessively large quantities of phosphorus.

No satisfactory explanation can be stated to account for the fact that flax, oats and rapeseed were unable to take up the total quantities of phosphorus supplied in the 0.03, 0.3, 1.0 and 3.0 ppm of phosphorus nutrient media, nor is it possible to explain why the three crops took up different approximately constant proportions of the phosphorus supplied in all media. For example, the quantity of phosphorus remaining after rapeseed had grown for 24 hours in 180 ml.

of the 3.0 ppm of phosphorus medium was many times larger than that initially supplied in the same quantity of the 0.03 or 0.3 ppm of phosphorus media. In spite of this fact rapeseed took up 77 per cent of the phosphorus initially present in each medium. The per cent utilization of phosphorus data indicate that whereas flax, oats and rapeseed were able to obtain phosphorus from media of widely different phosphate concentration, the three crops differed with respect to the total quantities of phosphorus each was able to obtain from any one medium. Oats was the most efficient extractor of phosphorus, rapeseed was less efficient than oats and flax was the least efficient.

Mgm. of phosphorus obtained from the nutrient medium

The quantities of elemental phosphorus supplied in 180 ml. of the 0.03, 0.3, 1.0, 3.0 and 30.0 ppm of phosphorus media were 0.0054 mgm., 0.054 mgm., 0.18 mgm., 0.54 mgm. and 5.4 mgm. respectively. Thus, no matter what proportions of the phosphorus supplied in the 0.03, 0.3, 1.0 and 3.0 ppm of phosphorus media were used by the crops the absolute quantities of phosphorus taken up were small. The absolute quantities in mgm. of phosphorus extracted from all but the 30.0 ppm of phosphorus nutrient medium were, in general, largest for oats, smaller for rapeseed and least for flax. The quantities of phosphorus taken from the media at each harvest agree very well with the increases in the total phosphorus contained in the plant materials at the corresponding harvests. For example, rapeseed and oats took 26.26 mgm. and 19.62 mgm. respectively, of phosphorus from the 30.0 ppm of phosphorus medium in seven days. The increases in the total

phosphorus contents of rapeseed and oats were approximately 24.8 mgm. and 21.3 mgm. of phosphorus respectively.

Summary and Conclusions

A nutrient solution experiment was conducted to investigate phosphorus uptake by flax, oats and rapeseed from nutrient media containing 0.03, 0.3, 1.0, 3.0 and 30.0 ppm of phosphorus. Radioactive tracer P32 was employed to measure the quantities of phosphorus removed from the media.

The yields of rapeseed plant materials were much larger than those of oats and flax. The yields of fresh and oven dry rapeseed plant material grown in all media approximately doubled in seven days. The yields of oats grown in the low phosphate concentration media doubled, while in the media of higher phosphate concentration they quadrupled. The yields of flax were variable. The moisture contents of fresh flax, oat and rapeseed plant materials were independent of the phosphate concentration of the media in which the plants had grown. Fresh oat and rapeseed plant materials contained a slightly greater proportion of moisture than did the flax plant materials.

Assuming that the total quantity of phosphorus contained in the plant materials existed in solution, the concentrations of phosphorus in all plant solutions increased with increasing phosphate concentration in the nutrient media to which the plants had been subjected. Rapeseed contained larger total quantities of phosphorus than did flax or oats. Rapeseed and oats produced slightly larger

yields of dry plant material when grown in the 3.0 ppm of phosphorus medium from which they obtained 4.0 mgm. and 2.6 mgm. respectively of phosphorus in seven days, than when grown in the 30.0 ppm of phosphorus solution from which they obtained approximately 24 mgm. and 19 mgm. respectively of phosphorus. Thus, rapeseed and oats demonstrated a capacity to consume very large quantities of phosphorus which in turn appeared to reduce the growth of these crops. Flax took up slightly more phosphorus from the 30.0 ppm of phosphorus nutrient medium than from the 3.0 ppm of phosphorus medium, however, it did not consume luxury quantities of phosphorus as did oats and rapeseed.

All crops were able to obtain phosphorus from the very dilute 0.03 ppm of phosphorus nutrient medium. Oats took up 85 to 90 per cent, rapeseed took up 77 per cent and flax took up approximately 50 per cent of the phosphorus supplied in the 0.03, 0.3, 1.0 and 3.0 ppm of phosphorus nutrient media. The proportion of the phosphorus taken from the 30.0 ppm of phosphorus medium varied with the abilities of the crops to take up excessively large quantities of phosphorus.

On the basis of the data presented, a number of tentative conclusions can be stated. Flax, oats and rapeseed are able to obtain phosphorus from very dilute phosphate solutions. The three crops are unable to obtain all of the phosphorus supplied in the solutions. Oats is the most efficient extractor of phosphorus contained in solution, rapeseed is a less efficient extractor than oats and flax is the least efficient extractor of the three crops studied.

When supplied with large quantities of available phosphorus oats and rapeseed take up much more of that nutrient than they require for growth. In contrast, flax appears to take up only slightly more phosphorus than is required to promote optimum growth.

GREENHOUSE EXPERIMENT IV

Methods and Materials

A Neubauer (23) experiment employing radioactive tracer P32 was conducted to study the soil phosphorus feeding powers of flax, oats and rapeseed. The Neubauer technique involves growing a large number of seedling plants on a small quantity of soil and has been used to measure the levels of available phosphorus and other nutrients in soils. The seedlings rapidly form an extensive root system throughout the soil and exhaust the nutrient supply. Chemical analysis of the tops and roots of the seedlings makes it possible to determine the quantities of soil nutrients obtained by the plants. It was hypothesized that if the Neubauer method could be used to determine the level of available phosphorus in soils, the same method could be used to differentiate between the phosphorus feeding powers of different crops. When several crops are grown on one soil, the crop able to extract the most phosphorus from that soil must be the strongest phosphorus feeder.

The experiment contained five treatments of the three crops: flax, oats and rapeseed. Each treatment was replicated four times. Treatment I was a blank treatment in which the seedlings were grown in nutrient free silica sand. The soil employed in treatment II was the Balmoral series (26) high-lime soil used in greenhouse experiment I and II. The soils employed in treatments III, IV and V respectively were a Balmoral series high-lime soil (26), an Altona association

soil (6) and a Portage association soil (7). Some of the characteristics of the soils are listed in Table XXVIII.

Quantities of the soils were air dried and were thoroughly mixed to ensure homogeneity. Twelve 100 gm. samples each of the silica sand and the four soils were weighed out and spread in uniformly thin layers over separate $8\frac{1}{2}$ " by 11" sheets of paper.

One millicurie of carrier free P32 was obtained February 14 and was diluted to one litre. To prepare a solution containing 1 uc of P32 per 10 ml. of solution, 100 ml. of the stock solution was diluted to one litre.

The sand and soil samples spread on the sheets of paper were moistened with distilled water and a 10 ml. aliquot of the solution containing 1 uc of P32 per 10 ml. was metered out as evenly as possible over the soil surface. Upon drying, each sample was rolled on the paper to ensure a thorough mixing of P32 throughout. Addition of tracer P32 to the soils, it was hoped, would make possible a determination of the quantities of exchangeable phosphorus available to each crop grown in each soil.

Twenty lots each of 100 flax, 100 oat and 100 rapeseed seeds were carefully selected for uniformity of size.

Plastic refrigerator containers measuring 3" by 3" by $3\frac{1}{2}$ " deep were used to grow the crops in the experiment. 100 gm. of nutrient free silica sand was evenly layered into the bottom of the containers. The 100 gm. portion of sand or soil was layered in on top of the sand. A second layer of 100 gm. of sand was placed over the sand or soil.

TABLE XXVIII
 SOME CHARACTERISTICS OF THE SOILS EMPLOYED IN THE NEUBAUER EXPERIMENT

	Balmoral	Balmoral	Altona	Portage
pH	7.8	7.9	7.6	7.8
Conductivity of satn. extract (mmhos per cm.)	.70	.55	.88	.78
Texture	SiCl	SiCl	FSL	L
% organic carbon	5.08	4.43	2.31	3.92
% inorganic matter	8.76	7.64	3.98	6.76
% inorganic carbonate	27.89	7.73	.25	.74
CaCO ₃ equivalent (%)	46.51	12.90	.41	1.25
NaHCO ₃ -extractable phosphorus (ppm)	6.8	6.2	7.9	11.6
Exchangeable potassium (ppm)	305.0	516.0	252.0	433.0

A glass tube 7 cm. long and 14 mm. in diameter was placed upright in the center of the container to facilitate watering. The 100 seeds of the crop to be grown in the container were spread evenly over the surface of the second sand layer. A final layer of 100 gm. of sand was placed over the seed.

Sufficient distilled water was added to saturate the soil and wet the sand to the surface on February 18. The containers were placed in a growth chamber in which the environmental conditions could be carefully controlled. The lids were left on the containers until February 23, by which date the plants first began to appear through the soil. The temperature in the growth chamber was maintained at 70° F. and the crops were subjected to 16 consecutive hours of light and 8 hours of darkness every 24 hours. Distilled water was added via the glass tubes in the quantities required to maintain optimum moisture conditions for plant growth.

All crops were harvested March 9, 19 days after seeding. The sand and soil was thoroughly but gently washed from the plant roots. The total plant materials, roots and tops, of each crop were dried in an oven at 90° C. and were weighed to determine the yields of dry plant material. The complete yields of rapeseed and flax plant materials were wet ashed. The oat plant materials were ground and a representative one gram sample from each was wet ashed. Samples of 100 flax, 100 oat and 100 rapeseed seeds were wet ashed. Aliquots of the ash solutions were taken for total phosphorus analyses and radioactive counting.

Results and Discussion

Tables XXIX, XXX and XXXI, respectively, list the plant populations, the yields of oven dry plant material, the total quantities of phosphorus in the plant materials grown on each soil, the quantities of seed phosphorus and soil phosphorus in the plant materials and the per cent recovery of P₃₂ added to the sand and the soils for flax, oats and rapeseed. Exchangeable phosphorus values determined for the soils with each crop were not reported.

Plant populations

The populations of rapeseed and flax plants were less than the 100 plants expected due partly to poor seed germination and partly to the inability of the tiny seedlings to push up through the damp sand layer covering them. To obtain an accurate estimate of the quantities of seed phosphorus and soil phosphorus in the plant materials produced, the number of rapeseed and flax plants in each container was counted when the crops were harvested. There were approximately 100 oat plants in each container because the per cent germination of oat seed was high and the seedlings had no trouble breaking through the sand layer after germination.

Yield of plant material

Oats produced much larger yields of plant material than did rapeseed or flax because oat seed is much larger than is rapeseed or flax seed and contains larger quantities of stored plant foods. The

TABLE XXIX

PLANT POPULATIONS, YIELD OF OVEN DRY PLANT MATERIAL AND PHOSPHORUS UTILIZATION DATA FOR FLAX

Treatment	Plant population	Yield of oven dry plant matter gms.	Total P. mgm.	Av. total P. mgm.	Seed P. mgm.	Soil P. mgm.	Av. soil P. mgm.	Av. % recovery of P32
I	68	.70	1.59	2.13				2.2
I	100	.88	2.56					
I	90	.97	2.34					
I	76	.65	2.02					
II	38	.52	.94	1.12	1.03	--	.06	0.8
II	52	.98	1.13		1.40	--		
II	44	.58	1.13		1.19	--		
II	46	.50	1.30		1.24	.06		
III	32	.50	.94	1.28	.86	.08	.09	1.5
III	56	.71	1.54		1.51	.03		
III	41	.51	1.23		1.11	.12		
III	46	.60	1.35		1.24	.11		
IV	44	.55	1.47	1.75	1.19	.28	.19	8.5
IV	65	.65	1.18		1.76	.08		
IV	67	.71	1.95		1.81	.14		
IV	54	.60	1.71		1.46	.25		
V	50	.70	1.76	1.81	1.35	.41	.39	6.5
V	54	.90	1.95		1.46	.49		
V	39	.45	1.30		1.05	.25		
V	67	.85	2.22		1.81	.31		

Average quantity of phosphorus in 100 flax seeds - 2.7 mgm.

TABLE XXX

PLANT POPULATIONS, YIELDS OF OVEN DRY PLANT MATTER AND PHOSPHORUS UTILIZATION DATA FOR OATS

Treatment	Plant population	Yield of oven dry plant matter gms.	Total P. mgm.	Av. total P. mgm.	Seed P. mgm.	Soil P. mgm.	Av. soil P. mgm.	Av. % recovery of P32
I	100	3.25	11.20	10.56	11.55	--	--	12.7
I	100	3.34	9.17					
I	100	3.20	10.57					
I	100	3.58	11.30					
II	100	3.60	11.62	11.02	11.55	.07	.07	7.0
II	100	3.60	10.85		11.55	--		
II	100	3.70	10.16		11.55	--		
II	100	3.80	11.45		11.55	--		
III	100	3.80	11.72	11.65	11.55	.17	.39	10.8
III	100	3.70	11.41		11.55	--		
III	100	3.50	11.30		11.55	--		
III	100	3.85	12.15		11.55	.60		
IV	100	3.30	11.37	11.81	11.55	--	.70	25.2
IV	100	3.30	11.37		11.55	--		
IV	100	3.30	11.82		11.55	.27		
IV	100	3.60	12.67		11.55	1.12		
V	100	3.60	13.19	13.18	11.55	1.64	1.63	27.0
V	100	3.80	12.55		11.55	1.00		
V	100	3.90	13.44		11.55	1.89		
V	100	4.10	13.54		11.55	1.99		

Average quantity of phosphorus in 100 oat seeds - 11.55 mgm.

TABLE XXXI

PLANT POPULATIONS, YIELDS OF OVEN DRY PLANT MATTER AND PHOSPHORUS UTILIZATION DATA FOR RAPESEED

Treatment	Plant population	Yield of oven dry plant matter gms.	Total P. mgm.	Av. total P. mgm.	Seed P. mgm.	Soil P. mgm.	Av. soil P. mgm.	Av. % recovery of P ₃₂
I	97	.51	1.64	1.66				6.3
I	85	.46	1.64					
I	92	.60	1.64					
I	91	.50	1.71					
II	87	.78	1.83	1.93	1.54	.29	.49	7.8
II	78	.48	2.02		1.61	.41		
II	91	.72	1.95		1.19	.76		
II	67	.85	--		--	--		
III	65	.68	1.83	1.87	1.15	.68	.46	11.1
III	86	.73	2.02		1.52	.50		
III	80	.58	1.54		1.42	.12		
III	86	.67	2.07		1.52	.55		
IV	93	.86	2.80	2.74	1.65	1.15	1.21	26.1
IV	82	.72	2.46		1.45	1.01		
IV	83	.83	2.60		1.47	1.13		
IV	87	.82	3.09		1.54	1.55		
V	93	.67	3.01	3.04	1.65	1.36	1.40	24.8
V	93	.54	3.23		1.65	1.58		
V	92	.61	2.68		1.63	1.05		
V	91	.70	3.23		1.61	1.62		

Average quantity of phosphorus in 100 rapeseed seeds - 1.77 mgm.

The yields of rapeseed and flax plant materials were approximately equal. The three crops produced nearly as much plant material when grown on the nutrient free silica sand of treatment I as when grown on the soils of treatments II to V.

Total phosphorus in the plant materials

The average quantity of phosphorus in 100 oat seeds was 11.55 mgm. as compared to 2.7 mgm. contained in 100 flax seeds and 1.77 mgm. contained in 100 rapeseed seeds. The above data explain why the oat plant materials contained so much more total phosphorus than did the flax and rapeseed plant materials. They do not, however, explain why, for an approximately equal number of rapeseed and flax plants, treatments II to V rapeseed contained a larger total quantity of phosphorus than did flax. In general the total quantities of phosphorus in all plant materials increased in the direction treatment II to treatment V indicating that the soil employed in each successive treatment contained more available phosphorus than did that of the previous treatment.

Seed derived phosphorus in the plant materials

The quantities of seed derived phosphorus in the rapeseed and flax plant materials were determined by multiplying the plant population by the quantity of phosphorus in one rapeseed or flax seed. Since the oat plant populations were equal it was assumed that the average quantity of seed derived phosphorus in the oat plant materials equalled the quantity of phosphorus in 100 oat seeds (i.e. 11.55 mgm. P.).

Soil derived phosphorus in the plant materials

Although the quantities of soil derived phosphorus in the plant materials were small the average values indicated that, except for treatment V, rapeseed obtained more soil phosphorus than did oats and oats obtained more than did flax. All crops removed more phosphorus from the non-calcareous treatments IV and V soils than from the calcareous treatments II and III soils. Rapeseed was able to extract phosphorus from all the soils employed in the study. Some of the treatments II, III and IV oat and treatment II flax seedlings must have lost phosphorus to the soils because, as was the case for treatment I, the plant materials produced contained less phosphorus than was contained in the seeds from which they had grown.

It was suggested that if flax had been grown for a longer period of time than were oats and rapeseed, it might have taken up as much or more soil phosphorus than did rapeseed. The oat and rapeseed plants had developed definite deficiency symptoms and had stopped growing when the crops were harvested. Although the dicotyledons of flax appeared to be developing a slight yellowish color, the plants were growing actively at harvest time. The soil phosphorus data reported indicated that flax had just begun to take up soil phosphorus when the crops were harvested.

Per cent recovery of radioactive tracer P32

Despite large differences in the sizes of flax and rapeseed plant populations, only slight variations were noted in the quantities of P32 recovered by the four replicates of each crop within a treatment.

The per cent recovery of P32 data reported are the average values for the four replicates of each crop subjected to the five treatments.

Flax recovered a smaller quantity of the P32 added to the sand of treatment I and the soils of treatments II to V than did oats and rapeseed. Oats and rapeseed recovered approximately equal quantities of the P32 from corresponding soils. All crops recovered much larger quantities of the P32 added to the non-calcareous treatments IV and V soils than from the calcareous treatments II and III soils. Oats and rapeseed recovered as much as one-quarter of the P32 added to the non-calcareous soils and only about one-tenth of that added to the calcareous soils.

The soil phosphorus utilization data and the per cent recovery of P32 data, although determined independently, each support the findings of the other. For example, the soil phosphorus utilization data for treatments II to V showed that oats and rapeseed took up more soil phosphorus than did flax. The per cent utilization of P32 data showed that oats and rapeseed used a larger proportion of the total exchangeable phosphorus of each of the soils than did flax.

The experimental data indicated that when flax, oats and rapeseed were subjected to the conditions of the Neubauer method, the soil phosphorus feeding powers of oats and rapeseed were shown to be equal. Flax took up less soil phosphorus than did the other crops.

Summary and Conclusions

A Neubauer experiment was conducted to investigate the soil

phosphorus feeding powers of flax, oats and rapeseed. Large numbers of plants were grown on 100 gm. portions of four Manitoba soils.

Equal numbers of flax and rapeseed plants produced approximately equal quantities of oven-dry plant material. Oats produced much larger quantities of plant materials than did the other two crops because oat seeds contain a larger reserve of food than do rapeseed or flax seeds. The rapeseed plant materials contained larger total quantities of phosphorus than did the flax plant materials, even though 100 flax seeds contain more phosphorus than do 100 rapeseed seeds. The total quantities of phosphorus in the oat plant materials were much larger than those in the rapeseed and flax plant materials. With the exception of treatment V oats, rapeseed obtained more phosphorus from all soils employed in the investigation than did oats and flax. Oats and rapeseed recovered a larger proportion of the P₃₂ added to the sand of treatment I and the soils of treatments II to V than did flax. All crops took up more soil phosphorus and recovered a larger proportion of the added P₃₂ from the non-calcareous treatments IV and V soils than from the calcareous treatments II and III soils.

On the basis of soil phosphorus utilization data and P₃₂ recovery data it was concluded that the soil phosphorus feeding powers of the three crops were greatest for oats and rapeseed, and least for flax.

GREENHOUSE EXPERIMENT V

A greenhouse experiment employing soils known to contain low levels of available phosphorus was conducted to study the soil phosphorus feeding powers of flax, oats and rapeseed. In planning the experiment, it was decided that the crops would be allowed to grow for a longer period of time than they had grown in previous greenhouse experiments to ensure that differences between the crops in their soil phosphorus feeding powers would be expressed in the data collected, if such differences do exist.

A superficial investigation of the potted soils in which the greenhouse experiment II flax, oats and rapeseed had grown indicated that there was a marked concentration of rapeseed roots one and one-half inches below the soil surface in the fertilizer band area. In contrast, oat and flax roots formed a fine, evenly spaced meshwork throughout the soil volume. It was suggested that the concentration of rapeseed roots in the fertilizer band area of the soil may have been due to a natural concentration of roots in that area or that root development may have been stimulated by the readily available supply of phosphorus. To test these hypotheses phosphate fertilizer was banded into the soil two inches above the lower soil surface in one treatment of experiment V.

The phosphorus deficient soils chosen for the experiment were an Almasippi association (7) non-calcareous soil and a Gilbert association (5) calcareous soil. Two fertilizer treatments of the

three crops were grown on the Almasippi soil and three fertilizer treatments of the three crops were grown on the Gilbert soil. Table XXXII lists a number of the characteristics of the two soils.

The three fertilizer treatments were: treatment I, a check treatment in which no phosphate fertilizer was added to the soils; treatment II, a phosphate fertilizer treatment in which 40 ppm of phosphorus in the form of finely divided KH_2PO_4 crystals was mixed throughout the soils; and treatment III, a phosphate fertilizer treatment in which 10 ppm of phosphorus (i.e. 10 ml. of a solution containing 8.78 gm. KH_2PO_4 per litre) was banded into the Gilbert soil two inches above its lower surface. Sufficient potassium was added, in the form of finely divided KCl crystals, to the treatments I and III soils to make the quantity of available potassium in each soil equal that in the corresponding treatment II soil.

The purposes of the check treatments were to determine how much plant material flax, oats and rapeseed would produce when grown on phosphate deficient soils and to determine whether the crops differed in the amounts of soil phosphorus they were able to extract. The Almasippi soil treatment I was replicated six times. The Gilbert soil treatment I was replicated eight times.

The purposes of the treatments II were to determine how much plant material would be produced and how much phosphorus would be utilized when the crops were grown on the same soils if the supplies of available phosphorus were plentiful. The Almasippi and Gilbert soil treatments II were replicated four times.

TABLE XXXII
 SOME CHARACTERISTICS OF THE SOILS EMPLOYED IN THE GREENHOUSE
 EXPERIMENT

	Almasippi	Gilbert
pH	7.2	7.9
Conductivity of satn. extract (mmhos per cm.)	1.06	2.94
Texture	F.S.L.	S.L.
% organic carbon	2.34	3.31
% organic matter	4.03	5.76
% inorganic carbonate	--	3.74
CaCO ₃ equivalent (%)	--	6.23
NO ₃ -nitrogen (ppm)	24.0	144.0
NaHCO ₃ -extractable phosphorus (ppm)	6.6	5.5
Exchangeable potassium (ppm)	245.0	54.0
% hygroscopic moisture	2.1	2.0
% moisture at field capacity	24.5	16.9

Quantities of the soils were gathered and were air dried. To accomplish the thorough mixing of KH_2PO_4 required for the preparation of treatment II soils 22 kg. of air dry soil was evenly spread over a 3' by 12' sheet of paper and 2 kg. of the soil was spread over a 3' by 3' sheet of paper. 4.1224 gm. of KH_2PO_4 (i.e. 40 ppm of phosphorus calculated on the basis of 24 kg. of air dry soil) was sprinkled as evenly as possible over the 2 kg. portion of soil. The soil and fertilizer mixture was rolled for five minutes to produce a homogeneous mix which was then sprinkled evenly over and thoroughly mixed with the 22 kg. portion of soil. The same procedure was used to mix KCl throughout the treatments I and III soils.

2 kg. portions of the prepared soils were weighed into one-half gallon glazed porcelain pots. The solution containing 10 ppm of phosphorus was banded into the treatment III Gilbert soils at seeding time. Germinated seed was planted May 27 and the pots were placed in the greenhouse. Populations of four oat plants, four rape-seed plants and fifteen flax plants were grown. 20 ppm of nitrogen in the form of an NH_4NO_3 solution was added to both soils June 2 and June 22. An additional 40 ppm of nitrogen was added to the Almasippi soil June 28. These quantities of nitrogen plus that initially present in the soils supplied more than enough nitrogen to grow the crops to maturity. The methods used in caring for and harvesting the crops were similar to those described under the methods and materials section of experiment I. The crops were harvested July 29.

At harvest time oats had headed out, rapeseed had produced some seed pods and flax was beginning to form seed balls. The plant materials were dried at 90° C. for a twelve hour period and were cooled and weighed to determine the yields of oven dry plant material. The plant materials were finely ground in a Wiley mill and a representative two gm. sample of each was wet ashed. Aliquots of the ash solution were taken for total phosphorus analyses.

A superficial investigation of root development by the crops in the potted soils was conducted. The 2 kg. cylinders of soil and root material were removed from the pots and were cut in half lengthwise. One-half of each cylinder was placed flat side up on a wire mesh and a gentle stream of water was used to wash some of the soil away from the plant roots without changing their positions. A visual estimation of root concentration in the different areas of the soil was made for all crops within each treatment.

Results and Discussion

The Gilbert soil was gathered from one small area in a field and was transported to the University in several cloth bags. The soil was laid out to air dry on three large sheets of paper. The three large quantities of soil were not thoroughly mixed to ensure homogeneity before the soil was prepared and put in pots. As a result, it was observed when the crops were grown that the soil used to prepare four replicates of treatment I was much more fertile than that used to prepare another four replicates of that treatment.

The more fertile check treatment is referred to as treatment Ia. The quantities of soil used to prepare the treatments I and II Almasippi soils and treatments I, Ia, II and III Gilbert soils were thoroughly mixed to ensure homogeneity within the treatment. The yields of plant material in gms. of oven dry wt., the per cent phosphorus in the plant materials and the total quantities of phosphorus in mgm. contained in the flax, oat and rapeseed plant materials grown on the Almasippi and Gilbert soils are listed in Table XXXIII.

Yields of oven dry plant material

The yields of oven dry plant material showed that even though the treatment I Almasippi soil and the Treatments I and Ia Gilbert soils contained equal quantities of NaHCO_3 -extractable phosphorus, the Almasippi soil produced the largest quantities of all plant materials. The treatment II Almasippi soil produced larger yields of all plant materials except rapeseed than did the treatment II Gilbert soil.

Almasippi soil. Treatment I flax and rapeseed produced equal quantities of plant material. Oats produced slightly more plant material than did the other two crops. Treatment II plant material yields decreased in the order oats, flax, rapeseed, and were only slightly larger than were the check treatment yields. Rapeseed showed sulfur deficiency symptoms and although flowers were produced it did not set seed. Had the supply of available sulfur been plentiful, treatment II rapeseed probably would have produced larger yields

TABLE XXXIII

THE YIELDS OF PLANT MATERIAL, THE PER CENT PHOSPHORUS IN THE PLANT MATERIALS AND THE
TOTAL QUANTITIES OF PHOSPHORUS IN THE PLANT MATERIALS

Crop	Soil	Treatment	Yield of oven dry plant materials in gm.	% P. in plant materials	Total mgm. P. in plant materials
Flax	Almasippi	I	9.32	.19	18.17
"	"	II	12.12	.26	30.98
Oats	"	I	12.92	.20	25.61
"	"	II	15.98	.36	57.86
Rapeseed	"	I	9.28	.19	17.83
"	"	II	10.77	.42	45.28
Flax	Gilbert	I	1.11	.11	1.20
"	"	Ia	4.57	.25	11.31
"	"	II	6.56	.34	22.23
"	"	III	3.43	.27	9.20
Oats	"	I	2.33	.21	4.87
"	"	Ia	7.90	.21	16.14
"	"	II	11.94	.24	28.65
"	"	III	8.39	.18	15.04
Rapeseed	"	I	1.80	.11	1.93
"	"	Ia	4.47	.12	4.56
"	"	II	13.63	.25	33.90
"	"	III	8.31	.13	10.67

of plant material.

Gilbert soil. The treatment I plant material yields were very small. Oats and rapeseed produced slightly more plant material than did flax. The yields of flax and rapeseed plant materials produced on the treatment Ia Gilbert soil were equal and were smaller than that of oats. Treatment II plant material yields decreased in the order rapeseed, oats, flax. Oats and rapeseed produced approximately two times as much plant material as did flax. Rapeseed and oats produced more than two times as much plant material as did flax when grown on the treatment III soil in which 10 ppm of fertilizer phosphorus was banded two inches above the lower soil surface.

Per cent phosphorus in the plant materials

The per cent phosphorus data indicated that the phosphorus contents of plant materials grown on the Almasippi soils were higher than those of plant materials grown on corresponding treatment Gilbert soils.

Almasippi soil. The phosphorus contents of all treatment I plant materials were equal whereas those of the treatment II plant materials decreased in the order rapeseed, oats, flax.

Gilbert soil. The phosphorus contents of treatment I rapeseed and flax plant materials were equal and were approximately one-half that of oats. The phosphorus content of treatment Ia flax plant material was slightly greater than that of oats and twice as great as that of rapeseed. The phosphorus content of treatment II flax plant material was one and one-half times as great as that of the

rapeseed and oat plant materials. The phosphorus contents of treatment III plant materials decreased in the order flax, oats, rapeseed.

The per cent phosphorus data and the yield data for the treatment I plant materials grown on the Almasippi soil showed that a given quantity soil phosphorus produced equal quantities of flax, oat and rapeseed plant materials. The per cent phosphorus data for the treatments Ia, II and III plant materials grown on the Gilbert soil showed that relative to oats and rapeseed flax took up phosphorus and stored it rather than using it to produce plant growth. The yield data suggested that oats and rapeseed made more efficient use, in terms of plant material production, of the phosphorus they acquired than did flax. For example, whereas the yields of treatment Ia flax and rapeseed were equal, the phosphorus contents of the plant materials were 0.25 and 0.12 per cent respectively.

Total phosphorus in the plant materials

Almasippi soil. Treatment I flax and rapeseed removed equal quantities of phosphorus from the Almasippi soil. Oats was able to extract approximately 42 per cent more phosphorus from that soil than was flax or rapeseed. The quantities of phosphorus removed from the treatment II soil decreased in the order oats, rapeseed, flax. Although the yield of treatment II rapeseed plant material was smaller than that of flax, it contained approximately 50 per cent more total phosphorus than did the flax plant material.

Gilbert soil. Although the quantities of phosphorus removed

from the very phosphate deficient treatment I Gilbert soil were small, oats extracted two and one-half times as much phosphorus as did rapeseed and four times as much phosphorus as did flax. Oats obtained 43 per cent more phosphorus from the treatment Ia Gilbert soil than did flax and 254 per cent more phosphorus than did rapeseed. Although the yields of flax and rapeseed plant materials were equal, phosphorus uptake by flax exceeded that of rapeseed by 6.7 mgm. The quantities of total phosphorus contained in the treatment II plant materials were much larger than those contained in the corresponding treatment I, Ia and III plant materials. Rapeseed removed the most phosphorus, oats removed less phosphorus than rapeseed, and flax removed the least phosphorus from the treatment II soil throughout which 40 ppm of fertilizer phosphorus had been mixed. Oats removed approximately 50 per cent more phosphorus from the treatment III soil containing 10 ppm of banded fertilizer phosphorus than did flax or rapeseed.

Measured in terms of phosphorus uptake by flax, oats and rapeseed, the Almasippi and Gilbert soils differed in their abilities to supply phosphorus for plant growth even though they were shown to contain equal quantities of NaHCO_3 -extractable phosphorus. The total quantities of phosphorus supplied by the soils varied for the three crops but showed a general decrease in the order Almasippi treatment I soil, Gilbert treatment Ia soil, Gilbert treatment I soil. The Almasippi soil was only moderately phosphorus deficient whereas the Gilbert treatment I soil was extremely phosphorus deficient.

The check treatment total phosphorus data showed that oats obtained more phosphorus from the phosphorus deficient soils than did flax or rapeseed. Flax obtained as much or more phosphorus from the soils as did rapeseed.

The fertilizer treatment II total phosphorus data showed that all crops took up much more phosphorus from the fertilized non-calcareous Almasippi soil than from the fertilized calcareous Gilbert soil. Had the supply of available sulfur in the Almasippi soil been plentiful it is suggested that, as was observed for the Gilbert soil treatment II plant materials, the Almasippi soil treatment II rapeseed plant material would have contained more total phosphorus than did the flax and oat plant materials.

Root development in the potted soils

The flax, oat and rapeseed root systems produced in the treatment II soils formed an extensive meshwork of relatively coarse secondary roots throughout the soil cylinder. Rapeseed and flax appeared to produce greater concentrations of secondary roots than did oats. The root systems produced in the Almasippi treatment I and the Gilbert treatment Ia soils in which the supplies of available phosphorus limited the growth of all crops contained a much more concentrated meshwork of very fine secondary roots than was observed in the root systems of the treatment II crops. The crops produced practically no root system in the extremely phosphorus deficient Gilbert treatment I soil. The hair-like roots that were produced extended only about two inches below the soil surface. Beyond that

depth practically no roots were observed.

Rapeseed did not produce a noticeably greater concentration of roots in the fertilizer band area than in other areas of the soil when the band was placed two inches above the lower soil surface as was done in the Gilbert treatment III soil. This observation implied that the concentration of rapeseed roots observed in the fertilizer band area of the greenhouse experiment II soil may have been due to a natural concentration of secondary roots at a depth of one to two inches below the soil surface. The three crops, however, appeared to produce a concentrated meshwork of secondary roots throughout the soil above and including the fertilizer band area and only a very few roots below the fertilizer band. These observations indicated that flax, oats and rapeseed grown on the Gilbert treatment III soil took up phosphorus from the fertilizer band.

Summary and Conclusions

A greenhouse experiment employing two soils known to contain low levels of available phosphorus was conducted to study the soil phosphorus feeding powers of flax, oats and rapeseed. A superficial investigation of root growth in the potted soils was conducted to study root production by the three crops, in soils containing plentiful supplies of available phosphorus, in phosphorus deficient soils and in a soil to which phosphorus fertilizer had been added in the form of a band located two inches above the lower soil surface.

The per cent phosphorus data and yield data showed that a

given quantity of phosphorus resulted in production of equal quantities of flax, oat and rapeseed plant materials grown on the non-calcareous Almasippi soil. When grown on the calcareous Gilbert soil oats and rapeseed made more efficient use of phosphorus in terms of plant material production than did flax.

Oats obtained significantly larger quantities of phosphorus from the check treatment soils than did flax or rapeseed. The quantities of phosphorus obtained by flax, although smaller than those of oats were significantly larger than, or approximately equal to, the quantities obtained by rapeseed. The three crops removed much more phosphorus from the fertilized soils than from the unfertilized soils.

The root studies indicated that when grown on soils containing plentiful supplies of available phosphorus flax and rapeseed produced slightly more concentrated meshworks of relatively coarse secondary roots throughout the soil than did oats. When grown under conditions of moderately severe phosphorus stress all crops produced highly concentrated meshworks of very fine secondary roots throughout the soils. Flax, oats and rapeseed grown under conditions of severe phosphorus stress produced practically no root systems at all. When phosphorus fertilizer was banded two inches above the lower surface of the Gilbert soil all crops produced a concentrated meshwork of secondary roots in the region of the soil above and including the fertilizer band area and only a very few roots below the fertilizer band.

On the basis of the experimental data presented it was concluded that oats is a stronger soil phosphorus feeder than is flax or rapeseed. Flax is able to remove more phosphorus from moderately phosphorus deficient calcareous soils than is rapeseed. Flax and rapeseed remove approximately equal quantities of phosphorus from moderately phosphorus deficient non-calcareous soils and from severely phosphorus deficient calcareous soils.

Flax, oat and rapeseed roots do not show a marked concentration in the fertilizer band area of the soil. It would appear that if the supply of available soil phosphorus is small all of the crops studied can obtain phosphorus from a phosphorus fertilizer band.

FINAL SUMMARY AND CONCLUSIONS

The phosphorus feeding habits of flax, a cereal and rapeseed were studied under field and greenhouse environmental conditions. The experimental data reported showed that the phosphorus feeding habits of the three crops differ in many respects. Hypotheses were suggested to account for the observed differences. Several short term greenhouse experiments were conducted to test these hypotheses.

A field experiment designed to determine the quantities of phosphorus taken up during the growing season and the rate(s) at which phosphorus is taken up for flax, wheat and rapeseed was located on a fallow and a stubble site. It was shown that rapeseed required much larger quantities of phosphorus than did wheat or flax when grown on both the fallow and stubble soils. Wheat and flax required approximately equal quantities of phosphorus. Wheat and rapeseed took up a larger portion of their total phosphorus requirements early in the growing season (i.e. prior to 60 days after seeding) than did flax. Flax took up phosphorus at an approximately constant rate throughout its growth and had obtained only one-half of that required by 60 days after seeding.

A greenhouse experiment was conducted in which populations of four flax, four oat and four rapeseed plants were grown in a high-lime soil. Radioactive tracer P32 was employed to determine the quantities of soil and fertilizer phosphorus in the plant materials and to make possible calculation of "A" values for the crops.

The four plant populations of oats and rapeseed produced larger yields of plant material and took up much larger quantities of phosphorus than did four flax plants. When exposed to conditions of phosphorus stress oats obtained nearly two times as much phosphorus from the soil as did rapeseed. These data constituted the first conclusive evidence that oats is a stronger soil phosphorus feeder than is rapeseed.

Phosphorus fertilizer banded into or mixed throughout the soil resulted in significant increases in the yields of oat and rapeseed plant materials. The yields of flax plant material indicated a slight response of flax to fertilizer phosphorus mixed throughout the soil but no response to the fertilizer phosphorus band application.

The per cent utilization of fertilizer phosphorus by the crops decreased in the order rapeseed, oats, flax, for all fertilizer treatments. Rapeseed made very efficient use of banded fertilizer phosphorus, oats made less efficient use of banded phosphorus than did rapeseed, and flax made practically no use of banded phosphorus. When grown in a soil containing a relatively high level of available phosphorus rapeseed showed a greater preference for phosphorus from a fertilizer band than did oats or flax.

"A" values determined for the crops with phosphorus fertilizer mixed throughout the soil suggested that whereas oats and rapeseed have equal soil phosphorus feeding powers flax is a slightly stronger soil phosphorus feeder than are the other two crops.

"A" values determined for the crops with band applications of fertilizer phosphorus decreased in the order flax, oats, rapeseed, suggesting that the soil phosphorus was most available to flax, less available to oats and least available to rapeseed.

To determine whether the differences among the crops with regard to utilization of banded fertilizer phosphorus and "A" value determination were due to actual crop differences or to the large differences in the yields of plant material, a similar greenhouse experiment was conducted employing radioactive tracer P32 and the same high-lime soil. Populations of four oat plants, four rapeseed plants and from seven to twenty-seven flax plants were grown. The larger flax plant populations produced yields of plant material that were comparable to, but somewhat smaller than the yields of oats and rapeseed.

Oats took up more soil phosphorus than did flax or rapeseed. Many of the larger flax plant populations took up approximately the same quantities of soil phosphorus as did rapeseed. The per cent utilization of banded fertilizer phosphorus by the crops decreased in the order rapeseed, oats, flax. Rapeseed derived just less than one-half of its total phosphorus from the fertilizer band. Oats and flax derived one-third and one-fifth respectively of their total phosphorus from that source. "A" values determined with flax were large and variable and showed no correlation with the size of flax plant population. "A" values determined with the three crops decreased in the order flax, oats, rapeseed.

It was concluded that the differences between flax, oats and rapeseed with regard to utilization of banded fertilizer phosphorus and "A" value determination were due to differences between the phosphorus feeding habits of the three crops.

Differences between "A" values determined with several crops for a single soil are the result of differences in the ratios of soil phosphorus to fertilizer phosphorus taken up by the plants. If the quantity of fertilizer phosphorus taken up is large in comparison to the quantity of soil phosphorus taken up, as was the case for rapeseed, the "A" value determined will be relatively small. If, on the other hand, the quantity of fertilizer phosphorus taken up is small in comparison to the quantity of soil phosphorus taken up, as was the case for flax, the "A" value determined will be relatively large.

The "A" value data presented for the crops under study indicated that rapeseed showed a greater preference for phosphorus from the fertilizer band than did oats or flax. Oats made relatively efficient use of fertilizer phosphorus, however, at the same time used much larger quantities of soil phosphorus than did rapeseed. Flax used soil phosphorus and derived only a small portion of its total phosphorus from the fertilizer band. Addition of a relatively large quantity of available phosphorus throughout a soil in which phosphorus fertilizer had been banded resulted in a proportionally smaller decrease in the utilization of banded phosphorus by rapeseed than by oats or flax.

The "A" value data showed that rapeseed takes up a relatively larger quantity of phosphorus from an area in which there is a high concentration of available phosphorus than does oats. Oats takes up a large quantity of phosphorus from a phosphorus fertilizer band, however, it also takes up a large quantity of phosphorus from other areas of the soil in which the phosphorus concentration is low. Flax takes up relatively much less phosphorus from a fertilizer band than does oats or rapeseed.

The previously stated data and that reported by Webber (33) showed that flax, oat and rapeseed "A" values determined for a representative group of Manitoba soils decreased in the order flax, oats, rapeseed. Yield data for the three crops showed that the increase in production of plant material resulting from a band application of phosphorus fertilizer was largest for rapeseed, smaller for oats and least for flax. "A" value data and yield data showed that an inverse relationship existed between the size of "A" value determined and the magnitude of the yield response to banded phosphorus fertilizer for the crops under study. The same relationship may exist for other crops. If this were so, it is conceivable that the "A" value determination might be employed to estimate the magnitudes of yield responses to band applications of phosphorus fertilizer for all crops grown on Manitoba soils.

Differences between the crops with respect to the total quantities of phosphorus required for growth to maturity and the rates at which phosphorus was taken up during the growing season

were attributed to differences in their growth habits. Differences between the crops with respect to utilization of banded fertilizer phosphorus and the ratios of soil phosphorus to fertilizer phosphorus taken up were not so easily accounted for. Several hypotheses were suggested to account for these latter differences:

1. Flax, oats and rapeseed differ in their abilities to obtain phosphorus from very dilute phosphate solutions. (e.g. the soil solution).

2. Flax, oats and rapeseed may specifically affect the availability of soil phosphorus (i.e. the crops may differ with respect to their soil phosphorus feeding powers).

3. The pH of the phosphorus fertilizer band may be more suitable for the growth and development in the fertilizer band area of rapeseed and oat roots than of flax roots.

In an attempt to test the validity of the suggested hypotheses several short term greenhouse experiments were conducted.

A nutrient solution experiment employing P³² to measure phosphorus uptake by flax, oats and rapeseed from nutrient media containing 0.03, 0.3, 1.0, 3.0 and 30.0 ppm of phosphorus was conducted.

It was shown that all crops were able to obtain phosphorus from the very dilute 0.03 ppm of phosphorus medium. When subjected to a medium containing a larger quantity of available phosphorus than was required for plant growth (the 30.0 ppm of phosphorus medium) rapeseed and oats took up luxury quantities of that nutrient.

Flax appeared to take up only slightly more phosphorus than was required to promote optimum plant growth. When subjected to media from which the plants should have been able to remove all of the phosphorus (the 0.03, 0.3, 1.0 and 3.0 ppm of phosphorus media) it was shown that oats removed 85 to 90 per cent, rapeseed removed 77 per cent, and flax removed about 50 per cent of the total phosphorus supplied. Thus the efficiency of phosphorus utilization from nutrient media for the crops decreased in the order oats, rapeseed, flax.

A Neubauer experiment in which large numbers of flax, oat and rapeseed plants were grown on 100 gm. portions of four Manitoba soils was conducted to study the soil phosphorus feeding powers of flax, oats and rapeseed. Previous to planting the crops, one μ c of P32 was mixed throughout each portion of soil.

Flax recovered a smaller proportion of the P32 added to the soils than did oats or rapeseed. Oats and rapeseed recovered approximately equal proportions of the P32 from corresponding soils. All crops recovered a larger proportion of the P32 added to the non-calcareous soils than of that added to the calcareous soils.

All crops extracted more soil phosphorus from the non-calcareous soils than from the calcareous soils. With the exception of one soil studied, the soil phosphorus utilization data indicated that when subjected to the conditions of the Neubauer method the soil phosphorus feeding powers of the three crops decreased in the order rapeseed, oats, flax.

A greenhouse experiment employing a non-calcareous Almasippi soil and a calcareous Gilbert soil, both of which were known to contain low levels of available phosphorus, was conducted to study the soil phosphorus feeding powers of flax, oats and rapeseed. A band of phosphorus fertilizer was placed two inches above the lower soil surface in one treatment of the Gilbert soil to determine whether a concentration of flax, oat and rapeseed roots would be produced in the fertilizer band area of the soil. Populations of four oat plants, four rapeseed plants and fifteen flax plants were grown in two kg. portions of the soils. When harvested the oats were in head, the rapeseed was in flower and had set some seed and the flax had begun to form seed balls.

Data showed that oats obtained significantly larger quantities of phosphorus from the phosphorus deficient soils than did flax or rapeseed. Flax obtained more phosphorus from the moderately phosphorus deficient calcareous soil than did rapeseed. Flax and rapeseed obtained approximately equal quantities of phosphorus from the moderately phosphorus deficient non-calcareous soil and from the severely phosphorus deficient calcareous soil.

Root studies indicated that neither flax, oats nor rapeseed produced a noticeably greater concentration of roots in the phosphorus fertilizer band area than in other regions of the soil. Phosphorus utilization data suggested that if the supply of available phosphorus in the soil is small all crops can obtain phosphorus from a phosphorus fertilizer band.

On the basis of experimental evidence presented it was concluded that the phosphorus feeding habits of flax, cereals and rapeseed are different. Rapeseed takes up more phosphorus during its growth than does flax or wheat. Flax and wheat take up approximately equal quantities of phosphorus. Rapeseed and wheat take up a larger proportion of their total phosphorus requirement early in the growing season than does flax. Flax takes up phosphorus at an approximately constant rate throughout the growing season. Oats and rapeseed have capacities to consume luxury quantities of phosphorus, whereas flax takes up only enough phosphorus to support optimum growth. Of the three crops studied, oats is the most efficient extractor, rapeseed is a less efficient extractor than oats and flax is the least efficient extractor of phosphorus supplied in a solution.

Rapeseed makes very efficient use, oats makes less efficient use than rapeseed, and flax makes least efficient use of phosphorus supplied in a phosphorus fertilizer band. Thus, it would appear that rapeseed prefers to obtain phosphorus from an area of relatively high phosphate concentration; the fertilizer band, whereas flax prefers to obtain phosphorus from an area of relatively low phosphate concentration; the soil.

Data concerning the soil phosphorus feeding powers of the crops showed that oats is the strongest soil phosphorus feeder. Flax and rapeseed have approximately equal soil phosphorus feeding powers. These data coupled with the fertilizer phosphorus utilization data

explain why "A" values determined for the crops decreased in the order flax, oats, rapeseed. Rapeseed took up large quantities of fertilizer phosphorus and relatively little soil phosphorus. Oats took up more soil phosphorus and somewhat less fertilizer phosphorus than did rapeseed. Flax took up about the same amount of soil phosphorus as did rapeseed, however, it took up smaller amounts of fertilizer phosphorus than did either oats or rapeseed.

Rapeseed showed the greatest response, oats responded to a lesser degree and flax showed practically no response to banded fertilizer phosphorus. The inverse relationship noted between "A" values determined with the crops and degrees of response of the crops to banded fertilizer phosphorus indicate that the "A" value determination may afford a measure of the responsiveness of crops to banded fertilizer phosphorus.

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