INFLUENCE OF NUTRIENT APPLICATION ON ROOT PROLIFERATION IN THE FERTILIZER REACTION ZONE AND UPTAKE OF ADDED NUTRIENTS

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ABSTRACT

The objective of this study was to investigate the effects of nutrients applied in the band on root proliferation in the fertilizer band and the relationship between this root proliferation and uptake of added nutrients.

Root proliferation in the applied fertilizer zone was varied with nutrient added. Nitrogen and phosphorus when applied alone or in combination resulted in intensive root proliferation in the fertilizer band. Application of potassium alone or in combination with nitrogen and/or phosphorus resulted in no or only slight root development in the band.

Utilization of added nitrogen and phosphorus was closely related with the extent of root growth in the fertilizer band. Uptake of potassium was not closely related to the magnitude of root growth in the fertilizer band. These studies indicated that when nitrogen and phosphorus fertilizers are added in a band they should be combined for efficient root development in the band and efficient uptake of these nutrients. It was also shown that the beneficial effects of nitrogen on phosphorus uptake, when these two nutrients are combined in one band, may be partly due to the increase in root growth in the phosphorus fertilizer band when nitrogen is added.

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CHAPTER I

INTRODUCTION

During recent years, much attention has been given to the manner in which plants take up mineral elements, the exact nature of the processes involved, and the underlying reasons for variations among different species in their absorption of essential and non-essential mineral elements. The amounts of the various nutrient elements that can be absorbed by plants are strongly influenced by the ratios of various elements in the medium as well as by the absolute quantities present in available form in the root zone.

Nitrogen, phosphorus and potassium, alone or in combination, contribute differentially to root development. Kalra and Soper (39) reported differences among plant species in utilizing applied phosphorus. Later, Strong and Soper (73) demonstrated that variations in root development in the reaction zone and the absorption capacity of the root was mainly responsible for the variations in applied phosphorus uptake among plant species. It was emphasized that, with some plant species, proliferation of roots within the fertilizer reaction zone was responsible for increased phosphorus uptake.

The objective of this study was to determine the influence of nitrogen phosphorus and potassium fertilizers on the growth of roots within the fertilizer reaction zone and the influence of root proliferation in the fertilizer zone on the utilization of added nutrients. Wheat, buckwheat, flax and rape were used as test crops and a soil considered to be deficient in nitrogen, phosphorus and potassium was used for study.

CHAPTER II

LITERATURE REVIEW

A. Factors affecting root proliferation in Fertilizer bands.

The density of roots in the fertilizer band has a large influence on the rate at which nutrients are absorbed from the band. Since the fertilizer band volume is very small, it is inconceivable that a plant could utilize large amounts of fertilizer when only one percent or less of its root surface is in contact with the available nutrients. However, some plants utilize relatively large quantities of nutrients supplied in a band application. The quick growth or proliferation of roots within the fertilizer band, however, is essential. The extent of root development in the fertilizer band is influenced to varying degrees by the nutrient applied and plant species grown (54). Phosphorus and nitrogen appear to be the two plant nutrients which cause the greatest root proliferation.

Nitrogen or phosphorus applied in a band alone did not cause root proliferation in the band even though the other nutrient was supplied at high levels to the rest of the root system. Both had to be added to the band for efficient root proliferation (54). Soil phosphorus level did not affect the recovery of fertilizer phosphorus from the band provided there was root proliferation in the fertilizer band.

Schnapinger _et al_. (68) compared the relative effects of phosphorus and potassium on root proliferation and suggested that phosphorus is more effective than potassium. Racz _et al_., (61) using a P^{32} injection technique for measuring root development, noted an enhanced root development of wheat in the vicinity of the phosphorus band. Effect of potassium alone on root growth is almost negligible (50).

Ohlrogge (55) suggested certain distinct advantages of band applications of fertilizers at planting time for corn provided certain requirements were met: (i) Fertilizers must be placed where it will intercept secondary roots. The most efficient placement would be 2.54 - 7.62 cm to the sides of the seed and 2.54 - 7.62 cm below the seed. (ii) Nitrogen and phosphorus must be mixed together in the band for rapid root proliferation and efficient nutrient uptake.

Wilkinson et al. (80) showed that soybean secondary roots respond to localized placements of nitrogen and phosphorus with increased lateral root development. Nitrogen fertilizers increased endogenous auxin content which was thought to be invaluable in increased root branching. In root extract, tryptophan was found and root-growth activity was associated with it. Extent of root-growth activity was greater at high nitrogen levels than at low nitrogen levels. Wilkinson et al. (81) later reported that nitrogen fertilized roots had higher root-growth activity than roots fertilized with phosphorus or roots not fertilized with phosphorus or nitrogen. Root extracts from roots fertilized with nitrogen and phosphorus tended to promote lateral root branching more than did root extracts from roots not fertilized with nitrogen and phosphorus, or with nitrogen and phosphorus alone.

Miller and Ohlrogge (47), working with corn plants, observed that nitrogen mixed with phosphorus increased the utilization of phosphorus from the band at all soil phosphorus levels. The development of roots in the area of nitrogen and phosphorus placement appeared to be the most important mechanism responsible for these effects. Duncan and Ohlrogge (20) observed very little effect of nitrogen and phosphorus on root development when not added in a mixture. The root proliferation they noted, was the result of a rapid growth of smaller roots. The rate of growth of primary roots was not affected. Proliferation of smaller roots was unaffected by salt concentration. The rate of growth in fertilized soil was much greater than in unfertilized soil and continued to grow for 10-12 days. Roots in unfertilized soil stopped growing after a short period of time. In other green house experiments (21), they observed that the fertilized-soil volume had no effect on fertilizer uptake when phosphorus was applied alone, but it caused significant increases in uptake when nitrogen was added to the fertilizer. Uptake of phosphorus increased with the amount and surface area of roots in the fertilized soil and with the amounts of phosphorus applied but tended to decrease with increases in the phosphorus content of the plant.

Grunes (27) observed that oat root tips were damaged in one portion of the fertilizer zone. The findings indicated that plant roots did not grow into any of the fertilizer zones except the 2 to 3 and 3-4 cm zones when the source of phosphorus was monocalcium phosphate. In another experiment, he found that roots did not penetrate the static fertilizer zone. The average distance of root growth from the fertilizer was 2, 8 and 6 cm for MCP, MCP+ NH_4Cl, and MCP+Kcl, respectively.

Stanford and Dement (72) reported that roots of intact, nitrogen deficient oat plants proliferated rapidly when placed in contact with both nitrogen fertilized and unfertilized soils.

B. Placement of nitrogen, phosphorus and potassium

Widdowson and Cooke (79) suggested that P, PK, and NPK beside the seed were superior treatments than broadcasting these fertilizers for a number of crops. Prummel (60) compared broadcast and banded methods of application of increasing levels of nitrogen, phosphorus, and potassium. In general, banding was better than broadcasting. For cereals, banding of nitrogen was 1.20 times as effective as was broadcast applications, while banding of phosphorus was 2.45 times superior to broadcast applications. Prevention of fixation and better early growth as a result of localization of fertilizers near the seed at an adequate depth were given as some of the reasons for the sucess of the banded placements. Dudley (19) reported similar findings with superphosphate for wheat in Kansas. He noticed that row application of superphosphate was twice as effective as was a broadcast application.

Rich et al. (64) obtained very small differences in yield as a result of different methods of fertilizer placement on silage corn. The band application was fully as effective as plow-sole or other deep placements of either all or part of the fertilizer. They obtained more early growth of the crop by band placement than by deep placement.

Stanford and Nelson (70), using P^{32}, observed that the percentage of phosphorus derived from the fertilizer was influenced by the position of the fertilizer with respect to the seed. Placement of fertilizers at seed depth and in bands on one or both sides of the seed generally resulted in greater utilization of the applied phosphorus by the plant than when placed in a single band above the level of the seed or in a single band three inches below the seed. Stanford et al. (71), in experiments with phosphorus and potassium, found very low recoveries of top dressed phosphorus. Dewitt (16), however, contradicted the findings of the above workers and suggested that at the higher rates relatively more phosphorus may be taken up from broadcast than from row applied fertilizer.

McVickar *et al.* (45) stated that banding potassium is highly beneficial on soils which are high potassium fixers, especially when low rates of potassium are applied. Band and broadcast methods were equally effective in influencing crop yields when higher rates of potassium were applied on soils with little potassium fixing capacity. Welch *et al.* (77) observed in their experiment with corn that less potassium was required to obtain a given yield when potassium was banded than when broadcast. In some cases, no rate of broadcast potassium equaled the yield produced by a given rate of banded potassium.

Nyborg and Henig (53) compared placement of fertilizers for barley, flax, and rapeseed. They obtained higher yields when fertilizers at high rates were placed away from the seed. Efficiency of phosphorus-fertilizers varied considerably with placement. Placing the phosphorus 2.5 cm directly below the seed was the best for both barley and flax and was superior to placing the fertilizer 5.0 cm from the seed. Placing the fertilizer 2.5 cm below the seed was better than placing it 2.5 cm to the side of the seed. Flax made much better use of both ammonium phosphate and triple superphosphate when placed 2.5 cm below the seed than when placed 2.5 cm to the side of the seed.

C. Phosphorus Uptake

Phosphorus uptake by plants grown in soil is affected by both soil and plant characteristics. Hagen and Hopkins (32), working with excised barley roots, observed an inverse relationship between the pH of the medium and phosphorus absorption by barley. They attributed this relationship to competitive inhibition of hydroxyl ions on phosphate uptake. Other workers (46), however, did not find any direct effect of pH on phosphorus absorption by intact plants over the pH range of 3 to 7. At pH 8, however, absorption of phosphorus was markedly reduced.

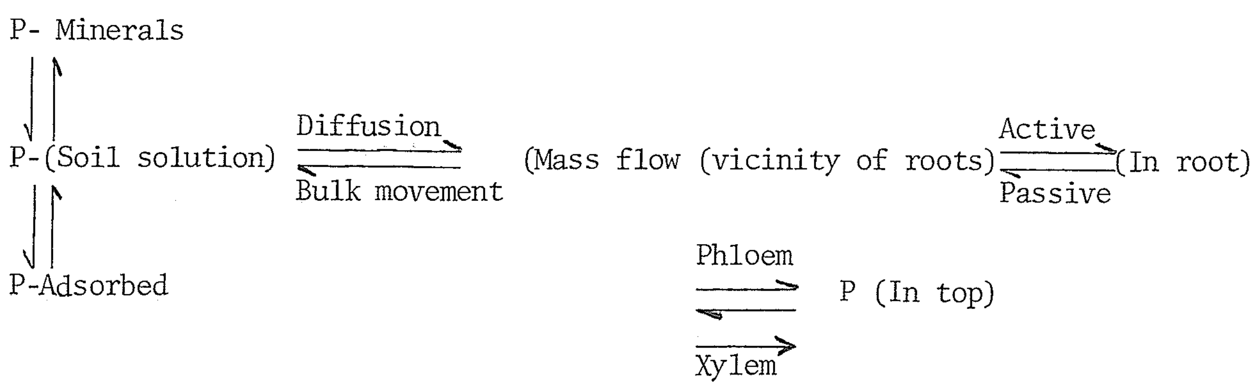
1. Soil Phosphorus Uptake

Utilization of native soil phosphorus is governed by a number of factors: viz. type of colloidal system (26), soil moisture (17), and soil volume (4).

Cornfield (15) noted a correlation in phosphorus uptake by oats, ryegrass, kale and tomato plants with their rooting intensities (root mass per mass of soil) in the soil in which they were grown. On increasing the soil volume in which the plants were grown, there was a reduction in the rooting intensity of each crop.

The nature of the crop species grown is also a determining factor in native phosphorus utilization. Kalra and Soper (39) showed that crops which made good utilization of soil phosphorus could not necessarily make good use of added phosphorus. They observed that soybeans utilized soil phosphorus to a larger extent than did rape. On the other hand, rape utilized more of the added phosphorus than did soybeans. Other workers (24, 51) have presented similar findings for a number of crops.

Fried and Shapiro (25) suggested the following relationships for phosphorus absorption by plants:



P = Phosphate ion.

They pointed out that the main process for phosphorus movement towards roots was mass flow but diffusion also accounted for part of the movement. Any factor that affects the conversion of phosphorus from solid to solution phase affects phosphorus uptake. Roots are in quilibrium only with solution phase phosphorus.

Hunter (35) concluded that the silicate ion, when present in large amounts, increased the availability of soil phosphorus by anion exchange.

2. Fertilizer Phosphorus Uptake

There are a number of factors which influence the utilization of added phosphorus. Some of them are: pH, moisture content of the soil, temperature, nature of the phosphorus fertilizer carrier, crop species, method and rate of phosphorus application, and nature of the fertilizer materials applied with phosphorus.

Lai and Lawton (43) stated that corn utilized more fertilizer phosphorus than the inter-planted crops of sesame or beans. The reason for the high phosphorus utilization by corn was attributed to the extensiveness of the corn root system. Hoagland (34), however, indicated that the magnitude of the root system does not necessarily represent the total active root absorbing surface.

Considerable evidence indicates that the percent uptake of fertilizer phosphorus by plants is inversely related to the level of soil phosphorus (12, 76).

An increase in phosphorus absorption has been observed with increases in soil moisture content (31, 78). Boatwright et al. (9) noticed that wheat plants did not absorb fertilizer phosphorus from dry soil. Alfalfa, however, was found to be able to absorb phosphorus from dry soil (18).

The influence of temperature on phosphorus availability has been studied by Barber (5). He found in laboratory studies that increases in incubation temperature of the soil increased subsequent availability of soil and fertilizer phosphorus to millet. Also, in field experiments, some relationship between the mean temperature and phosphorus availability was noticed. At low soil temperatures, reduced uptake of phosphorus has been observed (40, 44). Decreased permeability of root cells at low temperature was given as the reason for the decrease in absorption (42).

Bishop and MacEachern (7) studied the effect of rate of nitrogen, phosphorus, and potassium application on the uptake of these nutrients and found that the effect of increasing rates on the levels of these nutrients in plant tissues was predominantly linear. Increases in nitrogen levels in the plant were of much greater magnitude than increases in either phosphorus or potassium levels. Jacob et al. (37) also obtained increased percent utilization of added fertilizer phosphorus by increasing the rates of application.

a. Effect of Nitrogen on Phosphorus Uptake

The influence of added nitrogen on fertilizer phosphorus availability has been studied by a large number of workers for a variety of crops. (22, 28, 30, 48, 57, 66).

The influence of the NH_4^+ ion in increasing the fertilizer phosphorus uptake by crops has been described in various ways (2, 8, 11, 63). Blancher (8) concluded that the NH_4^+ ion increased the capacity of the plant to absorb phosphorus and did not affect the soil phosphorus availability. Caldwell (13) also found that nitrogen fertilizer increased the uptake of phosphorus. He cited the following possible reasons for the increased phosphorus uptake: (1) the influence of the nitrogen salt on the solubility of phosphorus material, (2) the interaction of ions in the culture medium, (3) some modification in the physiology of the plant, (4) root proliferation. He found the effect of various nitrogen carriers to be as follows: Ammonium Sulphate $>$ Ammonium Nitrate $>$ Calcium Nitrate. Thus the effect was primarily due to the function of the NH_4^+ ion. His results suggested that the effect of nitrogen on phosphorus absorption was brought about by chemical reactions between the nitrogen and phosphorus salts. Grunes (29) also found that the effect of nitrogen in increasing the phosphorus concentration in oat tops was due in part to increasing root growth, especially of fine roots which were high in absorbing capacity per unit weight.

Cole _et al_. (14) observed that increasing the levels of nitrogen increased phosphorus uptake by corn plants. The stimulation of the rate of phosphorus uptake with higher nitrogen levels suggests a connection between nitrogen metabolism and phosphorus uptake processes. Increased phosphorus uptake by nitrogen application was also found by Fine (23). Bouldin and Sample (10) noted the following sequence of fertilizer phosphorus uptake with different salts on two soils. The sequence on the soil with a pH value of 5.2 was: concentrated superphosphate $<$ concentrated superphosphate + potassium chloride $\leq$ concentrated superphosphate + Ammonium Chloride $\leq$ concentrated superphosphate + Ammonium Nitrate $<$ concentrated superphosphate + Ammonium Sulphate $\leq$ concentrated superphosphate + Potassium Nitrate. On the Soil with a pH value of 6.6, the order was: concentrated superphosphate $<$ concentrated superphosphate + Potassium Chloride $<$ concentrated superphosphate + Ammonium Sulphate $\leq$

concentrated superphosphate + Ammonium Chloride $\leq$ concentrated superphosphate + Ammonium Nitrate $\leq$ concentrated superphosphate + Potassium Nitrate.

Miller, Mamaril and Blair (49) found that ammonium sulphate had a large effect on the availability of phosphorus to corn plants. Nelson et al. (52) observed the effect of NP, and K in combination on the yield of oats. Nitrogen and phosphorus together were equally as responsive as was NP and K in combination. Olson and Dreier (57) also emphasized the superiority of the NH_4^+ ion over that of the NO_3^- ion in increasing fertilizer phosphorus utilization. Rennie and Mitchell (62) noted increased phosphorus uptake from ammonium phosphate and triple superphosphate as the amount of added nitrogen was increased. Riley and Barber (65), observed that ammonium fertilized soybeans absorbed more phosphorus and had a higher phosphorus concentration than nitrate fertilized soybeans.

Zuev and Golubeva (82) observed that depletion of nitrogen in winter wheat plants sharply inhibited phosphorus absorption and decreased the ratio of its inclusion in fractions of organic compounds. Transport of absorbed phosphorus from roots to shoots was also inhibited by the nitrogen deficiency. Similar results have been reported by Thien and McFee (74) for corn. The results of these workers suggested the existence of a nitrogen requiring metabolite in influencing the efficiency of phosphorus absorption and translocation mechanisms.

b. Effect of Nitrogen with Potassium on Phosphorus Uptake

Heslep and Black (33) observed increased phosphorus uptake by admixture with nitrogen and potassium salts. Similar results were obtained by Grunes and Krantz (27). Reduced diffusion of phosphorus from phosphatic fertilizers and less fixation by the soil was suggested as the possible reason for higher phosphorus uptake.

c. Effect of Potassium on Phosphorus Uptake

Fine (23) noticed that application of potassium with phosphorus in the fertilizer band had no effect on the recovery of fertilizer phosphorus as measured by oats, corn, and alfalfa on potassium deficient soil.

d. Effect of Nitrogen on Potassium Uptake

Acquaye and MacLean (1) showed that ammonium applied alone or after addition of potassium depressed potassium uptake by oats grown in a sandy loam soil in the green house. When NH_4^+ was added prior to potassium addition at the time of seeding, however, NH_4^+ increased potassium uptake. Barker, Maynard and Lachman (6) observed a depression in potassium uptake by tomato plants when excessive amounts of ammonical nitrogen was supplied. Axley and Legg (3) recommended the application of the nitrate source of nitrogen when potassium is simultaneously applied.

CHAPTER III

MATERIALS AND ANALYTICAL METHODS

1. SOIL: A Pine-Ridge soil was used in all the green house experiments conducted. The soil was collected from the 0 - 15 cm depth on September 25th, 1969. It was air dried, crushed, sieved through a 0.63 cm screen and thoroughly mixed. A sub-sample of 2.0 kg was passed through a 2.0 mm sieve and retained for analysis. Some characteristics of the soil used are given in Table I.

2. SOIL ANALYSIS:

(a) Soil texture: Soil texture was determined by the pipette method (41).

(b) pH: Soil pH was determined on a soil-water saturated paste using a glass and calomel electrode on a pH meter.

(c) Cation exchange capacity: The cation exchange capacity of the soil was determined as outlined by Peech *et al*. (58).

(d) Total nitrogen: A method outlined by Jackson (36) was used to determine the total nitrogen content of the soil.

(e) Sodium bicarbonate extractable phosphorus: The soil was extracted using 0.5 M $NaHCO_3$ at pH 8.5 and the phosphorus extracted determined colorimetrically (56).

(f) Conductivity: The electrical resistance of an extract from a saturated soil-water paste was measured using a conductivity bridge.

(g) Organic matter: The organic matter content of the soil was determined by the CO_2 method described by Peech *et al*. (69).

(h) $CaCO_3$ equivalent: The carbonate content of the soil was determined by the manometric method described by Skinner *et al*. (69).

TABLE I

SOME CHARACTERISTICS OF THE EXPERIMENTAL SOIL

Soil Association	Texture	Total N (%)	NO_3-N (ppm)	Na HCO_3 extractable-P (ppm)	NH_4-Ac extractable-K (ppm)	pH	$CaCO_3$ equivalent (%)	Conductivity (mmhos/cm)	C.E.C. (me/100g.)	Organic Matter (%)	Field Capacity (%)
Pine-Ridge	Loamy Sand	0.187	3	3	35	7.8	0.84	0.4	15	3.63	20.6

(i) NO_3 - N: The nitrate nitrogen content of the soil was determined using the phenoldisulphonic acid method (67).

(j) NH_4 - Ac Extractable K: Exchangeable potassium was determined by extracting the soil with 1.0 N NH_4 Ac. The potassium extracted was determined by using a Baird-Atomic KY-22 flame photometer (59).

(k) Field capacity: Field capacity moisture content was determined by saturating the soil with water, allowing for free drainage and then determining the moisture content of the soil.

3. EXPERIMENTAL DESIGN: All experiments were placed in a completely randomized block design and conducted in the greenhouse. All treatments in each experiment were replicated four times.

4. CROPS: In the first greenhouse experiment, the following crops were used:

i. Wheat (Triticum aestivum, L.) var. Manitou.

ii. Buckwheat (Fagopyrum esculentum, Moench.) var. Tokio

iii. Flax (Linum usitattissimum, L.) var. Noralta.

iv. Rape (Brassica napus) var. Target.

Wheat and rape were grown in the 2nd and 3rd experiments. Only wheat was grown in the 4th experiment.

5. PREPARATION OF P^{32} LABELLED PHOSPHORUS FERTILIZER:

Carrier-free P^{32} was obtained from the Atomic Energy of Canada, Ltd., Ottawa. P^{32} labelled sodium dihydrogenphosphate monohydrate and monocalcium phosphate monohydrate were used in experiments III and IV, respectively. The preparation of the fertilizers is briefly outlined below:

Adequate quantities of Na $H_2PO_4 \cdot H_2O$ or $Ca(H_2PO_4)_2$ H_2O were dissolved in a small volume of distilled water. Carrier free P^{32}, H_3PO_4 in HCl, was added so that a solution of approximately 10 μc P^{32} per 40 mg of P^{31} was prepared. All solutions were prepared in polyethylene containers. The solutions were evaporated to dryness on a sand bath and the isotopically labelled crystals ground.

6. GREEN HOUSE TECHNIQUES:

In all experiments, 2.0 kg of air dried soil was placed in one-half gallon glazed porcelain pots. The seeds were placed at a depth of 1.27 cm. Twenty seeds per pot were planted for flax and eight seeds per pot were planted for the remainder of the crops. The amount and placement of nitrogen, phosphorus, and potassium are discussed along with the result obtained for each experiment. The nutrients were mixed throughout the soil or placed into plastic cylinders (2.8 cm internal diameter and 3.6 cm long) containing a small volume of soil.

After planting and fertilization, the pots were watered to field capacity. The amount of water required to maintain the soils at or near field capacity was determined by weighing the pots. The plants were watered daily or as required.

The crops were thinned to four plants per pot except for flax in which the number of plants per pot was twelve.

7. HARVESTING AND PREPARATION OF THE PLANT SAMPLES:

The plants were harvested by cutting the stems close to the soil surface. Harvesting was done 34 days after seeding in experiment I. The duration between seeding and harvesting was 48 days for the remaining experiments. The plants were then cut into small pieces, air dried, and dried in an oven at 65° C for 36 hours. The plants were weighed and finely ground. The plant roots were separated from the soil by placing the soil from each pot or plastic cylinder on a 2.0 mm sieve and washing with water. The roots retained on the sieve were dried at 65^{o} c and weighed.

8. ANALYSIS OF PLANT MATERIAL:

(a) Total nitrogen: The total nitrogen content of the roots and tops was determined by the Kjeldahl method as outlined by Jackson (36).

(b) Phosphorus:

(i) Total phosphorus: (wet ashing procedure). The total phosphorus content of the plant material was determined colorimetrically by the Vanadomolybdate yellow colour method (36).

(ii) P^{32} labelled phosphorus (fertilizer phosphorus): Radioactivity in the wet ashed plant solutions and standard solutions (a solution of the isotopically labelled fertilizer) was determined by using a liquid DM6 GM tube attached to a binary scaling unit, Nuclear Chicago Model 161A. The radioactivity of the standard solution was measured within one hour of determining the radio activity present in the plant samples. The amounts of fertilizer phosphorus utilized (mg) by the plants was calculated using the following equation:

$$\frac{\text{Radioactivity of plant sample (C.P.M.)}}{\text{Radioactivity of standard (C.P.M.)}} \times \text{amount of fertilizer added} \times \frac{\text{Sample weight}}{\text{Yield per pot}}$$

Fertilizer phosphorus absorbed by the plants when subtracted from total phosphorus absorbed by the plants represented the amount of soil-phosphorus taken up by the plants.

(c) Total potassium: One-half g of finely ground plant tops were shaken on a reciprocal shaker for one hour with 100 ml of 1.0N NH_4 Ac.

adjusted to pH 7.0 and containing 250 ppm Li as $LiNO_3$. One-tenth or 0.2 g samples were used when roots were analyzed. The potassium extracted was determined by using a Baird-Atomic KY-22 flame photometer.

CHAPTER IV

PRESENTATION OF EXPERIMENTAL METHODS AND RESULTS

Experiment I

Several workers (39, 73, 75) in Manitoba have conducted field and green house trials to investigate the phosphorus feeding habits of a number of crops. They studied the effect of method of application, sources of phosphorus, and amounts of added fertilizer phosphorus on the utilization of added phosphorus by plants. In greenhouse experiments, they noted that crops differed in their fertilizer phosphorus utilizing capacity. They attributed the differences in fertilizer phosphorus utilization among plant species to variations in the amounts of roots within the fertilizer band and to variations in the phosphorus absorption capacity of the roots.

An experiment was thus conducted to determine if nutrients other than phosphorus would enhance root growth in a fertilizer band. Potassium was selected for study using wheat, buckwheat, flax and rape as test crops. An attempt was made to observe if there existed some relationship between root growth in the band and potassium uptake.

The main source of nitrogen used was ammonium nitrate (NH_4NO_3). Phosphorus was applied as monoammonium phosphate ($NH_4H_2PO_4$) and potassium as potassium chloride (KCl). Ammonium sulphate was used to supply 10 ppm sulphur. Nitrogen and phosphorus were added at rates of 80 and 20 ppm, respectively. The amount of nitrogen supplied by the ammonium phosphate and ammonium sulphate was calculated and the remaining quantity added as ammonium nitrate. All the nitrogen, phosphorus, and sulphur was mixed throughout the soil.

Potassium was applied as KCl at 50 or 100 ppm K. Potassium, at 100 ppm, was mixed throughout the soil as finely ground KCl or added as pellets in a band in the plastic cylinders. The 50 ppm application of the potassium was placed as pellets in the plastic cylinders. There was a control treatment in which all the nutrients except potassium were added.

The placement of fertilizers in the plastic cylinders and placement of cylinders into the pots were as follows: One kg soil was placed in each pot. The plastic cylinders (2.8 cm internal diameter and 3.6 cm long) were then filled one half full of soil, the KCl fertilizer added and the cylinder filled with soil. The cylinder containing the soil plus fertilizer was then placed in the center of each pot and another 800 g of soil added. The soil in the plastic cylinders weighed about 28 g which constitued approximately 1.5 percent of the total soil weight in the pot. The seeds were then planted and covered with 200 g soil and watered. Wheat, buckwheat, flax, and rape were grown for 34 days. The plants were then harvested, root and top yields obtained, and the potassium content of both the roots and tops determined. The results obtained are shown in Table 2.

Significantly higher yields of tops for all crops except flax were obtained when 100 ppm potassium mixed throughout the soil than when 50 or 100 ppm K was banded in the cylinders. The yield of tops also indicated that potassium deficiency was a limiting factor for the growth of all crops. Total yield of roots was closely related to top growth, with the highest yield of total roots being obtained in the pots which produced the greatest yield of tops.

TABLE 2

YIELD OF ROOTS (mg) AND TOPS (g) AND (%) OF TOTAL ROOTS IN CYLINDER AS INFLUENCED BY ADDED POTASSIUM

Crop yield		Control	KCl (100)[1]	KCl (100)[2]	KCl (50)[2]
			Treatment		
Wheat roots in cylinder	(mg)	1.7[a3]	7.2[a]	6.7[a]	7.5[a]
total roots	(mg)	39[c]	210[a]	120[b]	147[b]
tops	(g)	0.28[b]	1.28[a]	0.85[a]	0.88[a]
(%) of roots in cylinder		4.35	3.42	5.58	5.10
Buckwheat roots in cylinder	(mg)	2.7[a]	9.0[b]	5.2[a]	8.5[b]
total roots	(mg)	47[c]	303[a]	167[b]	177[b]
tops	(g)	1.28[c]	4.77[a]	3.02[b]	3.25[b]
(%) of roots in cylinder		5.74	2.97	3.11	4.80
Flax roots in cylinder	(mg)	2.0[b]	4.0[a]	2.2[b]	1.7[b]
total roots	(mg)	61[b]	105[a]	90[ab]	100[a]
tops	(g)	0.62[b]	0.96[a]	0.79[ab]	0.88[a]
(%) of roots in cylinder		3.27	3.80	2.44	1.70
Rape roots in cylinder	(mg)	2.7[b]	8.0[a]	4.2[ab]	4.7[ab]
total roots	(mg)	56[c]	252[a]	121[b]	117[b]
tops	(g)	1.08[c]	2.27[a]	1.58[b]	1.71[b]
(%) of roots in cylinder		4.82	3.17	3.47	4.01

1. KCl mixed throughout the soil.
2. KCl banded (placed in cylinder).
3. Duncan's Multiple Range Test.
   Treatments followed by the same letter within each crop are not significantly different at the 0.05 probability level.

The amount of buckwheat, flax, and rape roots in the soil in each cylinder was significantly increased above that of the control treatment when 100 ppm K was mixed in the soil. Placing the potassium in the cylinder did not significantly increase root growth in the cylinders except when buckwheat was grown. The amount of roots in each cylinder followed trends similar to those noted for the total quantities of roots obtained from each pot.

The percent of total roots present in the soil in the cylinder did not vary greatly with treatment. The percent of roots present in the cylinder, however, was slightly greater when potassium was placed into the cylinder than when mixed throughout the soil for wheat, buckwheat, and rape. This indicates the potassium in the cylinder caused a slight proliferation of roots in the fertilizer band.

The uptake of potassium by roots and tops and percent utilization of added potassium is presented in Table 3. The highest total uptake of potassium for all crops was recorded when 100 ppm potassium was mixed throughout the soil. Total potassium uptake was much less when the potassium was placed in the cylinders than when mixed into the soil. The roots of all crops contained only small amounts of potassium. Potassium uptake by the unfertilized plants was very low. Utilization of added potassium by wheat, buckwheat, flax and rape in a period of 34 days was mainly a function of crop species and plant yield. Regardless of the method of application, the highest uptake of potassium was observed for buckwheat. This crop also produced the highest yields of dry matter.

Root growth in the cylinders containing the banded potassium did not appear to affect potassium uptake from the band. Since the greatest

TABLE 3

UPTAKE OF POTASSIUM BY ROOTS AND TOPS (mg/pot)

AND PERCENT UTILIZATION OF ADDED POTASSIUM.

Crop	Control	Treatment KCl (100)[1]	 KCl (100)[2]	 KCl (50)[2]
Wheat roots	0.1	1.3	0.9	1.0
tops	2.4	69.5	38.6	36.6
total[3]	2.5[c]	70.8[a]	39.5[b]	37.6[b]
Percent uptake of added K[4]		34.15	18.48	17.51
Buckwheat roots	0.2	1.5	0.8	0.7
tops	11.2	116.2	56.5	49.6
total	11.4[c]	117.7[a]	57.3[b]	50.3[b]
Percent uptake of added K		53.16	22.29	19.46
Flax roots	0.2	0.7	0.7	0.6
tops	4.6	32.1	17.1	14.9
total	4.8[c]	32.8[a]	17.8[b]	15.5[b]
Percent uptake of added K		14.02	6.50	5.36
Rape roots	0.2	2.0	0.8	0.7
tops	6.3	75.1	43.6	35.4
total	6.5[c]	77.1[a]	44.4[b]	36.1[b]
Percent uptake of added K		35.31	18.95	14.80

1. KCl mixed throughout the soil.
2. KCl banded (placed in cylinder).
3. Duncan's Multiple Range Test. Values followed by the same letter within each crop are not significantly different at the 0.05 probability level.
4. Percent uptake of added K =

$$\frac{\text{K uptake with K added - K uptake without K added}}{\text{Amount of K applied}} \times 100$$

yields, highest potassium uptakes and greatest utilization of the added potassium fertilizer occurred when 100 ppm potassium was mixed throughout the soil, it would appear that these crops were not able to utilize efficiently the potassium placed in the cylinders. Since there was little or no root proliferation within the band, the uptake of potassium from the band may have been restricted by the lack of a sufficient quantity of roots within the small volume of soil contained in the cylinder.

Experiment II

The utilization of potassium by several crops and the influence of added potassium on root growth was studied in the previous experiment. It was found that the utilization of added potassium was greater from broadcast than from banded treatments. Root proliferation in the potassium fertilizer band was only slight and was not enough to bring the uptake of potassium equal to that of the broadcast treatment. The study was therefore further extended to observe the effects of nitrogen, phosphorus, and potassium alone or in various combinations on root proliferation in the fertilizer bands and the influence of root proliferation on the uptake of these nutrients.

Ammonium Nitrate (NH_4NO_3), monocalcium phosphate monohydrate $Ca(H_2PO_4)_2.H_2O$, and potassium chloride (KCl) were used as sources of nitrogen, phosphorus, and potassium, respectively. These nutrients were added at rates of 50 ppm nitrogen, 20 ppm phosphorus, and 50 ppm potassium. All the nutrients were placed in the plastic cylinders as was described for experiment I. Two cylinders were placed in each pot for all treatments except for treatments 7, and 8 where the number of cylinders per pot was three and one, respectively. The cylinders were placed in positions which maintained an equal distance from all plants grown in the pots. The treatments used are outlined below:

Treatment No.

1. P and K in separate cylinders, no N added.
2. N and K in separate cylinders, no P added.
3. N and P in separate cylinders, no K added.
4. P and K in one cylinder, N in second cylinder.
5. N and K in one cylinder, P in second cylinder.
6. N and P in one cylinder, K in second cylinder.
7. N in one cylinder, P in second, and K in third cylinder.
8. N, P, and K all in one cylinder.

Wheat and rape were planted as previously described. The crops were grown for 48 days, roots and top weights obtained and the roots and tops analyzed for nitrogen, phosphorus and potassium.

The yield of roots and tops obtained are shown in Table 4. The highest yield of both rape and wheat tops were obtained when all three nutrients were supplied. The yield of wheat tops was very low when no potassium was supplied. The yield of tops of rape was lowest when phosphorus was not added. The yield data thus indicate that all three nutrients tested were present in insufficient amounts in the soil for the growth of wheat and rape. The total yield of wheat roots followed trends similar to that noted for wheat tops. Total root weights for rape were also greatest when all three nutrients were applied. However, a rather large root weight was recorded for both wheat and rape when only phosphorus and potassium were applied. The amounts of roots in the cylinders and percent of total roots in the cylinder indicate that phosphorus applied with nitrogen and/or potassium enhances root growth of wheat in the

TABLE 4

YIELD OF ROOTS (mg) AND TOPS (g) OF WHEAT AND RAPE

Crop yield	Treatment 1		2		3		4		5		6		7			8
	(P)[1]	(K)	(N)	(K)	(N)	(P)	(PK)	(N)	(NK)	(P)	(NP)	(K)	(N)	(P)	(K)	(NPK)
Wheat roots in cylinder (mg)	cde[2] 6.2	cde 5.9	de 3.1	e 2.9	de 4.1	de 3.5	ab 15.5	cd 8.4	cd 7.5	cde 6.1	b 13.9	cde 7.2	de 4.3	cde 5.2	de 4.3	a 18.2
(%) roots in cylinder	2.03	1.93	1.39	1.30	3.12	2.67	3.92	2.38	2.03	1.65	3.33	1.72	1.18	1.43	1.18	3.97
total roots (mg)	bc 305		c 223		d 131		ab 395		b 369		ab 417		b 362			a 464
tops (g)	c 1.63		d 1.17		e 0.79		ab 2.16		abc 2.07		ab 2.16		bc 1.93			a 2.45
Rape roots in cylinder (mg)	d 5.8	d 3.7	d 3.1	d 3.3	d 5.3	d 6.7	bc 12.4	d 6.5	cd 8.6	d 7.2	ab 14.2	d 5.9	d 7.3	d 6.5	d 4.8	a 16.7
(%) roots in cylinder	1.67	1.06	1.46	1.55	3.35	4.24	3.26	1.71	2.34	1.96	4.15	1.73	2.61	2.32	1.72	4.53
total roots (mg)	a 346		bc 212		c 158		a 380		a 367		a 342		ab 279			a 368
tops (g)	bc 1.76		d 0.97		c 1.75		a 2.55		a 2.33		a 2.36		ab 2.27			a 2.55

1. Brackets denote nutrients placed in cylinder.
2. Duncan's Multiple Range Test. Treatments followed by the same letter within each crop are not significantly different at the 0.05 probability level.

fertilizer band. Phosphorus or nitrogen applied alone was not very effective in increasing root growth in the band. The proliferation of roots of rape in the cylinders followed trends similar to that noted for wheat. The greatest amount of roots (not significant) was found when all three nutrients were applied in one cylinder for both crops.

Table 5 presents the utilization of nitrogen, phosphorus, and potassium by wheat and rape. Percent utilization of applied nutrients is listed in Table 6.

Maximum utilization of nitrogen by both crops was observed when all nutrients were applied in one cylinder. This treatment also produced the highest yields of roots and tops. Similar findings have been reported by other workers (33, 71). Nitrogen uptake by both crops when all three nutrients were applied was greater than when only one or two nutrients were applied. Although there was a significant difference between root growth in the cylinder between treatment 6 and 8 for wheat, nitrogen uptake by wheat was similar when all three nutrients were applied, nitrogen uptake increased with increases in the amounts of roots found in the cylinders containing the nitrogen fertilizer. Since the highest yields were obtained on these treatments, it is possible that the high nitrogen uptake may have resulted from increased yields. It is also possible, however, that the increased yields were a function of higher nitrogen uptake due to increased root growth in the fertilizer band.

The percentage of fertilizer nitrogen utilized by the plants followed trends noted for nitrogen uptake (Table 6).

Phosphorus uptake by wheat was greatest when nitrogen was placed in the cylinder with the phosphorus. These findings are in agreement

TABLE 5

TOTAL UPTAKE OF NITROGEN, PHOSPHORUS, AND POTASSIUM

(mg/pot) BY WHEAT AND RAPE

Crop	Treatment							
	1	2	3	4	5	6	7	8
	(P)[1] (K)	(N) (K)	(N) (P)	(PK) (N)	(NK) (P)	(NP) (K)	(N) (P) (K)	(NPK)
Wheat								
Nitrogen	43.7 c[2]	44.9 c	33.4 c	69.0 b	68.9 b	75.6 ab	67.0 b	82.8 a
Phosphorus	3.6 c	2.9 c	3.2 c	5.6 b	5.3 b	7.5 a	5.5 b	7.5 a
Potassium	46.8 d	32.9 e	12.5 f	67.7 cb	72.6 ab	61.8 cb	58.0 cd	83.6 a
Rape								
Nitrogen	51.1 c	49.9 c	81.8 b	108.4 a	105.3 a	105.8 a	98.1 ab	115.7 a
Phosphorus	8.1 b	3.3 c	8.0 b	10.8 a	9.6 ab	11.4 a	9.9 ab	10.3 a
Potassium	37.0 cd	24.8 de	16.4 e	56.1 ab	58.7 ab	44.6 c	48.2 bc	66.4 a

1 Brackets denote nutrient placement in the cylinders.
2 Duncan's Multiple Range Test:
Treatments followed by the same letter within each crop are not significantly different at the 0.05 probability level.

with the findings of several other workers who observed increased uptake of phosphorus by the application of nitrogen and phosphorus in combination (22, 28, 30, 48, 57, 66). Phosphorus uptake by wheat when nitrogen and phosphorus was placed in separate cylinders was greater than when no nitrogen, phosphorus or potassium was applied (Table 5). Rape, however, utilized similar amounts of phosphorus in all treatments when all three nutrients were applied. This indicates that nitrogen need not be added in combination with phosphorus fertilizers for maximum utilization of phosphorus by rape. Rape was also able to utilize relatively large amounts of phosphorus even when no nitrogen or potassium was supplied. Phosphorus utilization by wheat, however, was extremely low when no nitrogen or potassium was supplied. In general, rape utilized greater amounts of phosphorus from all the treatments than did wheat. Absorption capacity of the roots, and total requirement of phosphorus by the crop are possible reasons for these differences. Similar results have been reported by Strong and Soper (73).

Phosphorus utilization by both crops appeared to be a function of yield and root growth in the fertilizer band. The percentage of fertilizer phosphorus utilized by the crops (Table 6) from the cylinders containing a large amount of roots was greater than from the cylinders containing smaller amounts of roots.

Potassium utilization by both crops was higher when it was placed with nitrogen and phosphorus. Wheat utilized more potassium than did rape (Table 5). The percentage of fertilizer potassium utilized by wheat was also greater than that utilized by rape (Table 6). Potassium uptake by both crops was very low when potassium was not applied.

TABLE 6

PERCENT UTILIZATION OF ADDED NUTRIENTS BY WHEAT AND RAPE

Crop	Treatment 1 (P) (K)[1]	2 (N) (K)	3 (N) (P)	4 (PK) (N)	5 (NK) (P)	6 (NP) (K)	7 (N) (P) (K)	8 (NPK)
Wheat								
Nitrogen	-	1.20	-10.39	25.32	25.16	31.82	23.23	39.10
Phosphorus	1.72	-	0.57	6.25	7.22	12.50	7.12	12.67
Potassium	34.34	20.41	-	55.22	60.08	49.33	45.54	71.07
Rape								
Nitrogen	-	-1.21	31.87	58.49	55.40	55.88	48.15	65.81
Phosphorus	12.00	-	11.75	18.75	15.75	20.25	16.50	17.50
Potassium	20.61	8.46	-	39.74	42.35	22.23	31.83	50.01

1 Brackets denote nutrients placed in cylinders.

Percent uptake

$$\text{of added nutrient} = \frac{\text{Uptake of nutrient added - uptake of nutrient without nutrient added}}{\text{mount of nutrient added}} \times 100$$

Uptake of applied nitrogen, phosphorus and potassium by wheat and rape was mainly a function of various combinations of nutrients applied in the band, plant yield and nature of crop species grown. The highest uptake of all nutrients by all crops was related to yield and the amount of roots in the fertilizer band or cylinders. Thus, root growth in the fertilizer reaction zone appeared to be responsible for the higher uptake, especially of nitrogen and phosphorus. Potassium uptake was also related to root growth when placed with nitrogen and phosphorus. This study indicated that phosphorus with nitrogen was mainly responsible for root proliferation in the fertilizer band. This resulted in a higher uptake of added nutrients and greater yields.

Experiment III

Wheat and rape crops grown in the 2nd experiment utilized greater amounts of nutrients from the fertilizer band when the applied nutrients caused root proliferation in the band. Uptake of nutrients and yield was closely related to the root development in the band. The study was further extended to include treatments in which the nutrients were mixed throughout the soil placed into the pots. Wheat and rape were grown. The rates of nutrient application were the same as for experiment II. The source of phosphorus was changed from monocalcium phosphate used in experiment II to sodium dihydrogen phosphate. The nutrients placed in the cylinders were mixed with the soil contained within the cylinder. In previous experiments the nutrients were banded into the soil in the cylinders.

The details of treatments used are given below:

Treatment No.

1. P and K mixed throughout the soil, no N added.
2. N and K mixed throughout the soil, no P added.
3. N and P mixed throughout the soil, no K added.
4. N in cylinder, P and K mixed throughout the soil.
5. P in cylinder, N and K mixed throughout the soil.
6. K in cylinder, N and P mixed throughout the soil.
7. P in one cylinder, K in second cylinder, N mixed throughout the soil.
8. N in one cylinder, K in second cylinder, P mixed throughout the soil.
9. N in one cylinder, P in second cylinder, K mixed throughout the soil.
10. P and K in one cylinder, N mixed throughout the soil.
11. N and K in one cylinder, P mixed throughout the soil.
12. N and P in one cylinder, K mixed throughout the soil.
13. N, P, and K all in one cylinder.
14. N, P, and K all in separate cylinders.
15. N, P, and K all mixed throughout the soil.

The phosphorus fertilizer, placed in the cylinders either alone or in combination with other nutrients, was labelled with P^{32}. Seeding was done and plants were grown as described for experiment II. After a period of 48 days, the plants were harvested, and the roots and tops analyzed for nitrogen, phosphorus and potassium.

The yields of roots and tops are presented in Table 7. The amount of roots in the cylinders and the amount of roots in the cylinders, expressed as a percentage of total roots, are listed in Table 8. Yield of wheat tops with all three nutrient supplied was usually greater than when only two nutrients were added (Table 7). Many of the differences noted, however, were not significant at the 0.05 probability level. Total root growth

TABLE 7

YIELD OF ROOTS (mg) AND TOPS (g) OF WHEAT AND RAPE

Crop	Treatment 1 PK	2 NK	3 NP	4 PK(N)[1]	5 NK(P)	6 NP(K)	7 N(P)(K)	8 P(N)(K)	9 K(N)(P)	10 (PK)N	11 (NK)P	12 (NP)K	13 (NPK)	14 (N)(P)(K)	15 NPK
Wheat															
total roots (mg)	ab[2] 230	b 194	c 94	a 248	ab 223	ab 238	ab 222	ab 226	a 251	a 262	a 270	a 258	a 256	ab 224	ab 231
tops (g)	bc 2.15	c 1.89	d 0.81	a 2.87	ab 2.53	abc 2.41	abc 2.43	abc 2.43	ab 2.58	bc 2.19	a 2.93	ab 2.49	abc 2.48	bc 2.13	ab 2.67
Rape															
total roots (mg)	c 404	c 392	c 361	ab 836	ab 883	ab 804	ab 766	ab 877	ab 916	ab 836	b 736	ab 769	a 970	ab 833	a 983
tops (g)	d 3.66	e 1.83	d 4.12	ab 6.17	ab 5.93	ab 6.09	bc 5.35	ab 5.95	abc 5.54	abc 5.69	a 6.24	abc 5.70	a 6.28	c 5.04	abc 5.84

1 Brackets denote nutrients placed in the cylinders.

2 Duncan's Multiple Range Test:
Treatments followed by the same letter within each crop are not significantly different at the 0.05 probability level.

followed trends noted for wheat tops and this finding agrees with those found in experiment II. Yield of tops when phosphorus and potassium were mixed throughout the soil or nitrogen and potassium were placed together in a cylinder, were significantly different from the treatments where either all the three nutrients were banded in separate cylinders or potassium was placed with phosphorus in one cylinder. Increased uptake of potassium from the previous two treatments may be a possible reason for higher yield of tops.

The yield of rape tops with all three nutrients applied was significantly greater than when only two nutrients were applied. Yield of tops in the treatment where no phosphorus was added was also significantly different from the treatments where either no nitrogen or no potassium was added. Total root growth of rape was closely related to top yields.

Root growth in the fertilizer reaction zone (cylinders) was greatest for both crops when all the three nutrients were placed in one cylinder (Table 8). This treatment, however, was not significantly different from the treatment with nitrogen and phosphorus in the cylinder for wheat, and nitrogen plus phosphorus and phosphorus plus potassium in the cylinder for rape. Thus, it appears that phosphorus plus nitrogen was mainly responsible for root proliferation in the fertilizer reaction zone. Phosphorus or nitrogen applied alone also resulted in considerable (non significant) root proliferation. Potassium applied alone did not appear to enhance root development in the fertilizer reaction zone. As mentioned previously, potassium did enhance root development slightly when applied with nitrogen and/or phosphorus.

Uptake of nitrogen, phosphorus, and potassium by these two crops are given in Table 9. Percent utilization of these nutrients are presented

TABLE 8

WEIGHT OF ROOTS IN CYLINDER (mg) OF WHEAT AND RAPE

Crop	Treatment 4	5	6	7		8		9		10	11	12	13	14		
	(N)[1]	(P)	(K)	(P)	(K)	(N)	(K)	(N)	(P)	(PK)	(NK)	(NP)	(NPK)	(N)	(P)	(K)
Wheat																
roots in cylinder (mg)	bcd 8.0	bcd 8.3	cd 3.3	cd 6.0	cd 3.9	cd 4.6	cd 5.0	bcd 7.8	cd 6.8	b 10.2	bcd 8.7	ab 14.7	a 16.2	cd 5.8	cd 4.5	cd 2.5
(%) roots in cylinder	3.23	3.72	1.38	2.70	1.75	2.03	2.21	3.10	2.71	3.89	3.19	5.69	7.23	2.58	2.00	1.11
Rape																
roots in cylinder (mg)	cd 15.5	cd 17.3	cd 8.4	cd 17.2	cd 6.7	cd 12.4	cd 7.2	cd 10.5	cd 16.4	ab 29.0	bc 20.1	a 34.4	a 38.9	cd 12.6	cd 12.4	cd 10.2
(%) roots in cylinder	1.85	1.95	1.04	2.24	0.87	1.41	0.82	1.14	1.79	3.46	2.73	4.47	4.01	1.51	1.48	1.22

1 Brackets denote nutrients placed in the cylinder.
2 Duncan's Multiple Range Test:
Treatments followed by the same letter within each crop are not significantly different at the 0.05 probability level.

in the Table 10. Utilization of nitrogen by wheat was highest in the treatment where nitrogen was banded alone and P and K were mixed throughout the soil. This treatment, however, did not provide a significantly greater amount of nitrogen than did treatments 5, 6, 9, 11, 12, 13 and 15. The higher uptake of nitrogen in treatments 4, 9, 11, 12 and 13 was probably due to the higher root development in the fertilizer band. Since the nitrogen fertilizer applied remains soluble, it's availability was quite high even when it was mixed throughout the soil. This was probably the reason for high uptake of nitrogen even when it was mixed throughout the soil. Nitrogen uptake by wheat when all three nutrients were applied was considerably greater than when only two nutrients were applied. Poor root growth in the fertilizer reaction zone in treatments 8, and 14 and placing the potassium in the band in treatment 7 and 10 may be one of the reasons for reduced uptake of nitrogen on these treatments.

There was a relationship between phosphorus uptake and root development in the fertilizer phosphorus band for wheat. Large uptake of phosphorus from the band usually occurred when large amounts of wheat rootswere present in the band. However, when phosphorus was placed with potassium and the nitrogen was mixed throughout the soil (treatment 10), the root development was similar to treatments with phosphorus and phosphorus plus nitrogen (treatments 5 and 12), but phosphorus uptake did not follow that order. All three treatments, in which only two nutrients were applied, supplied similar amounts of phosphorus to the wheat plant. In general, higher uptake of phosphorus was observed when it was banded than when mixed throughout the soil.

Rape utilized phosphorus quite efficiently from all the treatments

TABLE 9

UPTAKE OF NITROGEN, PHOSPHORUS AND POTASSIUM (mg/pot)

BY WHEAT AND RAPE

Crop	Treatment 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	PK	NK	NP	(N)[1]PK	(P)NK	(K)NP	(P)(K)N	(N)(K)P	(N)(P)K	(KP) N	(NK)P	(NP) K	(NPK)	(N)(P)(K)	N,P,K
Wheat															
Nitrogen	d[2] 52.0	cd 59.7	e 28.8	a 95.3	ab 81.1	ab 82.7	bc 73.1	bc 74.9	ab 80.4	bc 70.0	ab 83.5	ab 76.8	ab 82.5	bc 68.4	ab 84.3
Phosphorus	gh 5.5	h 3.6	h 4.3	bcde 10.1	bc 10.7	cde 9.0	bcde 10.3	cde 8.7	bcd 10.4	ef 8.2	cde 9.1	ab 12.0	a 13.4	fg 6.4	de 8.4
Potassium	d 54.1	de 39.1	e 16.5	a 92.5	abc 79.6	bcd 69.3	bc 78.6	bc 76.2	cd 70.4	cd 68.0	ab 87.8	abc 79.5	ab 86.5	cd 66.7	ab 88.6
Rape															
Nitrogen	c 51.8	c 41.5	b 103.4	a 135.8	a 134.8	ab 124.1	ab 122.2	ab 121.5	ab 117.3	ab 121.6	ab 124.3	a 129.2	a 137.4	ab 114.9	ab 118.8
Phosphorus	f 10.6	g 5.9	ef 12.5	cd 17.0	bcd 18.7	cd 16.9	bcd 18.0	de 15.8	bcd 18.2	bc 19.5	bcd 18.1	ab 20.5	a 22.6	cd 16.6	bcd 17.8
Potassium	cd 51.4	d 34.6	e 23.4	ab 86.8	a 97.9	ab 82.7	ab 76.4	ab 79.5	ab 79.1	ab 80.0	a 91.8	ab 84.5	a 96.4	bc 69.0	ab 82.0

1 Brackets denote nutrients placed in the cylinder.
2 Duncan's Multiple Range Test:-
Treatments followed by the same letter within each crop are not significantly different at the 0.05 probability level.

as compared to that of wheat. As was found for wheat, phosphorus uptake was greatest from the cylinders containing the largest amount of roots and when yields were high. This again indicates that root development in the fertilizer band influences the uptake of phosphorus fertilizer from the band. Rape utilized rather large quantities of phosphorus even when the phosphorus was mixed throughout the soil. The influence of placement on nutrient uptake noted above have been reported by several other workers (19, 47, 70, 76).

Potassium uptake by wheat when all three nutrients were added was greater than when only two nutrients were applied. The uptake of potassium was related to top yields. Since the highest wheat yields were usually obtained when root proliferation occurred and when large amounts of phosphorus and nitrogen were utilized by the wheat plants, potassium uptake from the cylinders also reflected root growth in the cylinders. The uptake of potassium when placed in the cylinders was similar to that when mixed throughout the soil. When potassium was placed with the N-P band, it's uptake was increased and the reason for this increased uptake was profound root proliferation in the N-P-K band. This is in agreement with the findings of Ohlrogge (54).

Potassium uptake by rape was similar for all treatments when all three nutrients were applied. However, potassium uptake by rape, when nutrients were placed in separate cylinders was significantly lower than when placed together in one cylinder. Method of application of potassium did not greatly influence potassium utilization by rape.

Percent utilization of applied nutrients by both wheat and rape followed the trends noted for total uptake of nutrients. When no potassium

TABLE 10

PERCENT UTILIZATION OF ADDED NUTRIENTS BY WHEAT AND RAPE

Crop	Treatment														
	1 PK	2 NK	3 NP	4 (N)[1]PK	5 (P)NK	6 (K)NP	7 (P)(K)N	8 (N)(K)P	9 (N)(P)K	10 (PK)N	11 (NK)P	12 (NP)K	13 (NPK)	14 (N)(P)(K)	15 N,P,K
Wheat															
Nitrogen	-	7.9	-23.2	43.3	29.1	30.7	21.1	26.9	28.3	18.1	31.5	22.8	30.8	16.4	32.2
Phosphorus	4.7	-	1.75	16.2	17.7	13.5	16.7	12.5	17.0	11.5	13.7	21.0	24.7	7.0	12.0
Potassium	37.6	22.6	-	76.0	63.1	52.8	62.0	59.7	53.9	51.5	71.3	63.0	69.5	50.2	72.1
Rape															
Nitrogen	-	-10.3	51.6	84.0	83.0	72.3	70.4	69.7	65.5	69.8	72.5	77.4	85.6	63.1	67.0
Phosphorus	11.7	-	16.5	27.7	32.0	27.5	30.2	24.5	30.7	34.0	30.5	36.5	41.7	26.7	29.7
Potassium	28.0	11.2	-	63.4	74.5	59.3	53.0	56.1	55.7	56.6	68.4	61.1	73.0	45.6	58.6

1 Brackets denote nutrients placed in the cylinders.

2 Percent utilization

$$\text{of added N or K} = \frac{\text{Uptake of nutrient with nutrient added - uptake of nutrient without nutrient added}}{\text{Amount of nutrient added}} \times 100$$

3 Percent utilization of added P was based on uptake of p^{32}.

was added and only N and P were mixed throughout the soil, the uptake of added nitrogen by wheat was low. Also, when no phosphorus was supplied, nitrogen utilization by rape was limited (Table 10).

The study showed that phosphorus, particularly when added in combination with nitrogen, increases root growth in the fertilizer band for both wheat and rape. This resulted in a larger utilization of added nutrients and greater yields. These studies confirmed the findings noted in experiment II. The studies also showed that when root proliferation occurs in the fertilizer band, a higher utilization of the added phosphorus results. Uptake of added nutrients proportionately increased with the yield of both crops. It was shown that uptake of nutrients increased with increase in root growth in the fertilizer reaction zone and that a certain level of root growth in the fertilizer band is essential for efficient fertilizer uptake.

Experiment IV

The previous experiments showed that phosphorus, particularly when combined with nitrogen, increased root growth in the soil near the site of fertilizer placement. Potassium when included in the N-P band had very little or no effect on root development in the band. Since other workers (47, 48, 49, 57, 62, 63, 65, 66) have shown a beneficial effect of nitrogen on fertilizer phosphorus uptake when applied together in a band, an experiment was conducted to determine if root proliferation resulting from nitrogen applications could explain the increases in fertilizer phosphorus uptake when nitrogen and phosphorus are combined as fertilizers. The experiment consisted of the following treatments replicated four times.

a) Phosphorus and potassium placed in the cylinder and 0, 20, 40, 60, 80 or 100% of added nitrogen placed in the cylinder.

b) Nitrogen and potassium placed in the cylinder and 0, 20, 40, 60, 80, or 100% of added phosphorus placed in the cylinder.

c) Nitrogen and phosphorus placed in the cylinder and 0, 20, 40, 60, 80 or 100% of the added potassium placed in the cylinder.

The portion of the nutrients not placed in the cylinders was mixed throughout the soil. One cylinder was centrally placed in all the pots. The rates and sources of all the nutrients were the same as for experiment III. Phosphorus in the cylinder was labelled with P^{32}. Seeds were planted as previously described. Wheat was grown for a period of 48 days. The plants were harvested, and the roots and tops analyzed for nitrogen, total phosphorus, radiophosphorus, and potassium.

The data on the total yield of roots, and tops and amounts of roots in the cylinder, are given in Table 11. Yield of wheat increased with increases in the amount of nitrogen placed in the cylinders containing phosphorus and potassium. These increases occurred when 60 percent or less of the nitrogen was placed with the posphorus and potassium. Additions of phosphorus to the cylinder containing nitrogen and potassium had no or very little effect on top yields. This was also true when increasing rates of potassium were applied to phosphorus and nitrogen in the cylinders. Yields of tops were low when phosphorus and potassium were placed in the cylinder and the nitrogen mixed throughout the soil.

Total root weights followed trends noted above for top yields. Total root yields were increased only when increasing amounts of nitrogen

TABLE 11

YIELD OF ROOTS, ROOTS IN CYLINDER (mg) AND TOPS (g) OF WHEAT

	N,P and K in cylinder	N,P and K mixed into the soil	Treatment: P and K in cylinder					N and K in cylinder					N and P in cylinder				
			(No)[1]	(N_{20})	(N_{40})	(N_{60})	(N_{80})	(Po)	(P_{20})	(P_{40})	(P_{60})	(P_{80})	(Ko)	(K_{20})	(K_{40})	(K_{60})	(K_{80})
Total roots (mg)	abcd[2] 259	abcde 249	de 201	e 188	cde 226	bcde 242	cde 229	bcde 248	bcde 244	abc 281	abcd 264	ab 298	bcde 225	bcde 240	bcde 223	abcde 250	a 314
Roots in cylinder (mg)	a 22.8	e 2.6	cd 9.5	bcd 10.8	abcd 12.8	abcd 17.5	abcd 19.8	de 8.8	bcd 11.2	ab 21.2	abc 19.6	ab 20.8	abcd 16.5	ab 20.6	abcd 15.7	a 21.5	a 21.6
% of roots in cylinder	8.80	1.04	4.74	5.74	5.66	7.23	8.64	3.54	4.59	7.54	7.42	6.97	7.33	8.58	6.73	8.60	6.87
Tops (g)	abcd 2.58	a 2.97	e 1.69	de 1.90	cde 2.25	abc 2.77	abc 2.84	ab 2.87	abcd 2.58	abcd 2.68	a 2.94	abcd 2.70	bcd 2.42	abc 2.77	abcd 2.64	abcd 2.69	abc 2.72

1 Brackets denote nutrient and percent of nutrient placed in cylinder.
2 Duncan's Multiple Range Test:
Treatments followed by the same letter are not significantly different at the 0.05 probability level.

were added to the phosphorus and potassium band. This reflects the large amount of root proliferation that can occur when nitrogen is applied to phosphorus fertilizer bands. The weight and percent of roots in the cylinder also increased when phosphorus was supplied to the nitrogen plus potassium band. Root growth in the cylinders was not significantly increased when potassium was applied to the phosphorus and nitrogen in the cylinders. These data thus indicate that nitrogen and phosphorus have relatively large influence on root growth in fertilizer bands. Potassium appears not to influence root growth in the fertilizer band.

Utilization of nitrogen, total phosphorus, fertilizer phosphorus, and potassium by wheat is given in the Table 12. Utilization of nitrogen was highest from the treatments when either all the nutrients were mixed throughout the soil or all of them placed in the cylinder. The reason for this increased uptake of nitrogen from the latter treatment is probably due to intensive root development in the applied fertilizer zone while in the former case the higher plant growth is the probable reason. In the treatments where nitrogen application was varied in the cylinder, uptake increased with increases in the levels of nitrogen applied in the cylinder. There was no significant difference among the above treatment when all of the applied nitrogen was mixed throughout the soil or 20 and 40% of it placed into the cylinder. The increases in nitrogen uptake were closely related to root growth in the cylinder. Thus increased root growth resulted in increases in nitrogen uptake.

Utilization of nitrogen was not significantly altered when variable amounts of phosphorus were added to the cylinders containing nitrogen and

TABLE 12

UPTAKE OF NITROGEN, TOTAL PHOSPHORUS, FERTILIZER PHOSPHORUS AND POTASSIUM (mg/pot) BY WHEAT

	N,P, and K in cylinder	N,P, and K mixed into the soil	Treatment: P and K in cylinder					N and K in cylinder					N and P in cylinder				
			(No)[1]	(N_{20})	(N_{40})	(N_{60})	(N_{80})	(Po)	(P_{20})	(P_{40})	(P_{60})	(P_{80})	(Ko)	(K_{20})	(K_{40})	(K_{60})	(K_{80})
Nitrogen	abc[2] 92.9	a 99.8	e 61.1	de 65.4	bcde 78.4	abc 89.5	abc 92.0	ab 97.2	abcd 82.0	abc 96.4	a 99.6	ab 97.5	cde 77.3	abc 95.9	abc 84.0	abc 94.6	a 99.5
Total Phosphorus	abc 10.1	abcde 8.5	e 6.4	de 6.8	bcde 7.5	abcd 9.0	abc 9.9	cde 7.3	bcde 7.5	bcde 7.6	ab 10.3	abc 9.8	abcde 8.4	abc 9.8	abcde 8.0	abc 9.8	a 10.7
Fertilizer Phosphorus	a 7.9	-	f 3.7	f 4.1	ef 4.5	cde 5.8	abcd 6.2	-	g 1.6	def 5.4	abc 7.3	abcd 6.8	bcde 5.9	ab 7.7	bcde 6.0	abcd 6.5	abcd 7.0
Potassium	a 70.4	a 72.9	e 48.2	c 53.0	bc 55.4	a 73.0	a 77.9	a 73.1	ab 68.9	a 71.3	a 79.8	a 72.4	ab 68.1	a 74.2	ab 68.7	a 72.6	a 75.7

1. Brackets denote nutrient and percent of nutrient placed in cylinder.
2. Duncan's Multiple Range Test.
   Treatments followed by the same letter are not significantly different at the 0.05 probability level.

potassium. The yield of tops in these treatments was also not greatly influenced. Growth of roots in the cylinder however, was increased when small amounts of phosphorus was added to the cylinder. Thus nitrogen uptake in those series of treatments was independent of root growth in the cylinders. Similar results were obtained in the previous two experiments.

Nitrogen uptake when the amounts of potassium were varied in the phosphorus plus nitrogen band was similar for all treatment except when all the potassium was mixed throughout the soil. When all the potassium mixed throughout the soil, the uptake of nitrogen was significantly lower than when 80% of the potassium was placed in the band. This treatment had the lowest yield of tops among these treatments. Root growth in the cylinders with phosphorus plus nitrogen and variable amounts of potassium added were also similar. Thus, no great influence on nitrogen uptake would be expected.

Total uptake of phosphorus and fertilizer phosphorus by wheat from the phosphorus plus potassium band increased as the amount of nitrogen added to the band was increased. This increase in phosphorus uptake is closely related to root growth in the cylinders. This indicates that part of the beneficial influence of nitrogen on phosphorus uptake when added in combination is probably due to increased root growth in the fertilizer band.

Uptake of total and fertilizer phosphorus increased as amounts of phosphorus placed with nitrogen and potassium was increased. These increase occurred only when 60% or less of the phosphorus applied was placed in the cylinders. These increases in phosphorus uptake were closely related to root growth in the cylinders. When 20% of the added phosphorus was in the cylinder, utilization of fertilizer phosphorus was 20 percent. On doubling the rate of phosphorus application (40 percent of the total applied phosphorus in the cylinder), uptake of fertilizer phosphorus was

33.75 percent. When the rates of phosphorus application in the band were increased to 60 or 80% of the total added, the percent utilization of added phosphorus was 30.40 and 20.15, respectively. Although the utilization of phosphorus was closely related to root growth, it is possible that the differences in the availability between mixed and banded phosphorus may have also influenced phosphorus uptake. Usually wheat plants utilize a lower percentage of broadcast phosphorus or phosphorus tilled into soil than of phosphorus banded with the seed.

Phosphorus uptake from the treatments where potassium application was varied in the phosphorus plus nitrogen band were similar. Data on the yield of roots in cylinder and tops were also similar in these treatments. This indicates that potassium addition had very little or no effect on phosphorus uptake.

Uptake of potassium by wheat was not highly variable. The only variation in potassium uptake was observed when nitrogen application in the phosphorus plus potassium band was varied. The two treatments, no nitrogen added and 20% of the total applied nitrogen added to the PK band were significantly different from the rest of the treatments. Very little top yield was obtained in these two treatments. Reduced uptake of potassium from the PK band is probably due to low root growth in the cylinders when no or small amounts of nitrogen were added. Thus, potassium uptake was related to top yields and root growth in the cylinders. Potassium uptake by wheat when the amounts of phosphorus or potassium were varied in the bands were similar although the amounts of roots in the cylinder varied in many instances. It thus appears that root proliferation has little or no influence on potassium uptake from fertilizer bands.

CHAPTER V

SUMMARY AND CONCLUSIONS

Considerable work in Manitoba has been conducted on the phosphorus nutrition of crops (38, 39, 73, 75). In field and greenhouse studies, it was shown that root development in the applied fertilizer phosphorus zone varied with crop species. In most cases higher uptake of fertilizer phosphorus was associated with intensive root development in the reaction zone. Greenhouse experiments were thus conducted to study the effects of nutrients other than phosphorus on root development in the applied fertilizer zone and the effect of this root growth on the utilization of applied nutrients. Nitrogen, phosphorus and potassium were selected for study.

First, the effect of potassium on root development was studied. Four crops, wheat, buckwheat, flax and rape were grown for a period of 34 days. Application of potassium in the fertilizer band did not stimulate root development in the fertilizer zone and consequently the uptake of potassium by all four crops was lower when potassium was banded than when it was broadcast. Very little root development in the fertilizer band, probably limited the uptake of potassium.

A second greenhouse experiment was conducted in which the effects of nitrogen, phosphorus and potassium on root development in the fertilizer band was studied. Wheat and rape where grown as test crops. Application of nitrogen, phosphorus, and potassium increased the yield of both crops over that of the control treatment. Root development in the fertilizer reaction zone was greatly increased when nitrogen was applied with phosphorus.

Root development was not or only slightly affected by potassium application to the fertilizer band. Uptake of nitrogen and phosphorus was found to be highest when large amounts of roots developed in the fertilizer band. Nitrogen uptake was greatest when it was placed in combination with either phosphorus or potassium. Nitrogen and phosphorus uptake was closely related to root growth in the fertilizer band. Potassium uptake was not related to root growth in the fertilizer band. However, potassium uptake was related to root growth when placed with phosphorus and nitrogen. Root proliferation appeared to be mainly a function of nitrogen and phosphorus application.

A third greenhouse experiment, similar to experiment II, was conducted to further study the influence of nitrogen, phosphorus, and potassium on root development in the fertilizer reaction zone and the uptake of applied nutrients. This study showed that phosphorus, particularly when added in combination with nitrogen, increases the root growth of wheat and rape in the fertilizer band. The increased root growth in the band was related to increased uptakes of the added nutrients and higher yields. This experiment further demonstrated that phosphorus and nitrogen when added in a band resulted in an extensive root development in the fertilizer band.

To determine the individual influences of nitrogen, phosphorus or potassium on root proliferation, a fourth greenhouse experiment was conducted. Variations in root development in the applied fertilizer zone were observed when various amounts of nitrogen were added to cylinders containing phosphorus and potassium. Increasing the rates of nitrogen application in the cylinder increased root proliferation in the cylinder and the uptake of applied nitrogen, phosphorus and potassium. Thus the beneficial effects of nitrogen on phosphorus uptake when nitrogen is mixed with phosphorus fertilizer is partly due to increased root growth in the fertilizer band. Similarly the levels of phosphorus in the cylinders containing nitrogen plus potassium also increased root growth in the cylinders.

Increasing the application of potassium in the cylinders containing nitrogen and phosphorus had very little or no effect on root development in the cylinder.

From these findings it was concluded that nitrogen and phosphorus are essential for root development in the fertilizer band whereas potassium plays a minor role. Root proliferation in the fertilizer band was usually associated with an increase in uptake of the added nitrogen and phosphorus and increased yields. Thus nitrogen and phosphorus should be added in combination for efficient utilization of banded nitrogen and phosphorus fertilizers. Root proliferation in the fertilizer band did not greatly influence potassium uptake.

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