THE UNIVERSITY OF MANITOBA

EFFECT OF METHOD OF PHOSPHORUS PLACEMENT ON YIELD AND PHOSPHORUS RECOVERY OF BARLEY, CANOLA AND FLAX

by

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ABSTRACT

Field studies and pot experiments were conducted to evaluate: the effect of method of phosphorus placement on yield and P recovery by barley, flax and canola; the effect of fall vs spring bands of N and P on barley yield and P recovery; and the effect of nitrogen carrier on yield and P recovery by barley, flax and canola. Phosphorus fertilization increased yields and P concentration of barley and canola. Seed row placement and split P placements were generally more effective in increasing yields than dual or separate bands of N and P spaced at 20 or 40 cm, at rates of 100 $kg.ha^{-1}$ N and 22 $kg.ha^{-1}$ P. Flax yields were not affected by phosphorus application by any method. Application of N, P and K at rates of 200 $kg.ha^{-1}$ N, 242 $kg.ha^{-1}$ P and 179 $kg.ha^{-1}$ K increased barley yields to a maximum of 5166 $kg.ha^{-1}$. Canola yields were not affected by rate of fertilization and similar yields were produced between rates of 100 $kg.ha^{-1}$ N and 22 $kg.ha^{-1}$ P and 100 $kg.ha^{-1}$ N, 242 $kg.ha^{-1}$ P and 179 $kg.ha^{-1}$ K. Response of barley to fall vs spring banded P was variable and neither time of application was consistently superior. Urea was as effective or more effective than ammonium sulphate or ammonium nitrate in increasing barley, canola or flax yields. Monoammonium phosphate was markedly more efficient in increasing midseason dry matter production of canola than triple super phosphate but did not affect flax yields.

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1. Introduction

Fertilizer inputs are a major component in today's intensive cropping system. The need for an efficient, convenient method of applying fertilizers has become increasingly important to producers and an option to the traditional methods of broadcasting or placing phosphorus in the seed row was sought. The concept of preplant bands of P, perhaps in a dual band with N, was introduced some years ago, and has the potential to overcome some of the problems associated with broadcast or seed row fertilizer applications. By preplant banding, fertilizer efficiency can be improved compared to broadcast applications, particularly in semi-arid moisture regimes where efficient moisture utilization is important. Banding provides an option to the inconvenience of handling fertilizer at time of seeding, as well as reducing the risk of seedling damage and delayed or reduced emergence which may occur by placing fertilizer in the seed row of small seeded crops such as flax and canola. Preplant banding has the advantage of fall or spring applications and is easily adapted into the producer's time schedule. Fall banding is also encouraged by fertilizer manufacturers to ease the demand for fertilizer storage facilities over the winter months and to extend the transportation season. Banding can be accomplished with adapted common tillage equipment, and thus does not require major machinery expenditures by producers. Banding also accomodates the combination of regular tillage operations with fertilizer application. Since P is a relatively immobile nutrient, placement of P below and close to the seed may help to encourage deeper, stronger root systems.

Previous research in Western Canada on P banding, and dual banding of N and P, has largely concentrated on the benefits of banding with cereal crops. The purpose of this investigation is to evaluate the effect of various methods of P placement on yield and nutrient recovery of canola, flax and barley. The focus of this study is on band, seed row and broadcast placements of P, rather than on rate of P application. Some experiments also include band placements of P with various sources of nitrogen to evaluate the effect of N carrier on P availability and P uptake by the plant.

2. Literature Review

Effect of P placement on crop emergence

Placement of nitrogen and phosphorus fertilizers in the seed row was found to delay and/or reduce emergence of five field crops (Nyborg, 1961). Tolerance to seed row placement of ammonium nitrate and monoammonium phosphate in increasing order was found to be flax, rapeseed, wheat, barley and oats. Percent emergence of wheat, barley and oats was only slightly reduced by the application of 45 $kg.ha^{-1}$ N and 20 $kg.ha^{-1}$ P in the seed row, although emergence was delayed by 9 to 12 days. An equivalent application of N and P in the seed row reduced flax and rapeseed emergence to zero. Seed row placement of P alone as monoammonium phosphate (MAP) or triple superphosphate (TSP), without additional N fertilizer, reduced rapeseed emergence to 55 % when applied at a rate of 10 $kg.ha^{-1}$, and flax emergence to 82 % at a rate of 5 $kg.ha^{-1}$ P. Emergence was delayed by 9 and 3 days respectively. Ammonium nitrate was more injurious to the seed than monoammonium phosphate or triple superphosphate, and resulted in a greater delay in emergence for any of the test crops. Delays or reductions in emergence were also more pronounced at low soil moisture contents than optimum soil moisture contents. The cause of injury to the seed is due to a direct toxic effect of the fertilizer, and particularly the presence of NH_3 (Nyborg, 1961). Also, an increase in osmotic pressure of soil solution from fertilizer salts impairs the availability of water, necessary for germination, to the seed, resulting in reduced emergence (Dubetz et al, 1959). The degree of injury to the seed is related to the type of crop, the type of fertilizer, soil texture, soil temperature and soil water content (Nyborg, 1961). Band placement an inch or more away from the seed, or broadcast applications of fertilizer reduce the risk of seedling injury.

Studies in Alberta have also shown emergence of flax and rapeseed to be more sensitive to seed row placement of P than barley emergence (Nyborg and Hennig, 1969). Emergence of barley was delayed by the application of 39 $kg.ha^{-1}$ P as MAP with the seed, while flax and rapeseed emergence was reduced when 15 to 20 $kg.ha^{-1}$ P was placed with the seed. However, seedling damage could be reduced by band placement of the fertilizer.

Effect of P placement on yield

Studies in Alberta have shown that the application of MAP at 39 $kg.ha^{-1}$ P resulted in yields of barley which were similar whether the P was placed with the seed or banded below the seed (Nyborg and Hennig, 1969). However, flax and rapeseed yields were reduced when 15 to 20 $kg.ha^{-1}$ P was placed with the seed. Flax yields were favored by band placement directly below the seed. A study conducted on two Manitoba soils comparing various band placments, with respect to distance placed from the seed, showed band placement directly below the seed to be more efficient in increasing flax yield than bands placed some distance to the side of the seed, thus supporting the findings of Nyborg and Henning (Sadler and Bailey, 1981). Only band placement directly below the seed of 10-30 $kg.ha^{-1}$ P and shallow side placement of 30 $kg.ha^{-1}$ P (1.5 cm. to the side and 0.5 cm. below the seed) resulted in greater yields than seed row placement of 5 $kg.ha^{-1}$ P. However, all band placements away from the seed resulted in greater recovery of applied P by flax than seed row placement.

Placement studies in Manitoba showed soybean yields and soybean P uptake to be greatest when monocalcium phosphate (MCP) was placed 2.5 cm directly below the seed, as compared to 5.0 cm below the seed, and 0, 2.5 or 5.0 cm to the side (Bullen et al, 1983). This sensitivity to band placement was partly attributed to the plant's root system. Band placement 2.5 cm directly below the seed appeared to be available to primary roots, yet not injurious to the seedling. Similarly, band placement 4 cm below the seed and 4 cm beside the seed resulted in higher oat yields than bands placed 8 cm directly below the seed (Prummel, 1957).

The efficiency of banding was again evident in field studies which compared five P placements: fall broadcast, spring broadcast, seed row, sidebanded, and band placement directly below the seed (Bullen et al, 1983). Band placement proved to be more effective than broadcasting in increasing both soybean yield and P uptake. Seed row placement increased soybean seed yields up to an application rate of 26 $kg.ha^{-1}$ but decreased yields at application rates of 52 $kg.ha^{-1}$. Banding directly below the seed was more effective than sidebanding at application rates of 13 $kg.ha^{-1}$ P or more. In summary, vegetative growth, seed yield, and P uptake of soybeans was more effectively increased with phosphate placed in a band rather than broadcast.

However, the benefit of bands decreased as distance between the band and the seed increased.

Band placement of TSP was noted to be markedly more efficient than broadcast applications in increasing yields of oats, maize, pulse crops, potatoes, and beets in the Netherlands (Prummel, 1957). On phosphate deficient soils ripening of maize was promoted and higher yields obtained when P was banded rather than broadcast. Ratios between the amount of fertilizer required to give the same yield for broadcasting and band placement averaged 2.45 for cereals, 1.90 for potatoes, 1.20 for beets, 2.90 for maize and 7.50 for pulse crops. Therefore the benefit of placed P was greatest for pulse crops and least for potatoes and beets. This was related to differences in the nature of the root systems of these crops, as will be discussed later.

Effect of soil P status on response to applied P

Field experiments in Illinois showed that less P applied as TSP was needed when banded, as compared to broadcast, to produce a specified corn yield on soils which tested low in available P (Welch et al, 1966). Little difference between banded and broadcast applications of P was found on a soil which had high levels of available P. The relative efficiency of broadcast P in terms of banded P (P broadcast/P banded) ranged from 0.64 to 0.88 on the P responsive sites. It was concluded that the relative efficiency of broadcast versus banded P was related to the initial P status of the soil. As the fertility status of soils is raised to a higher level by fertilization, the advantage of band application as compared to broadcast application was expected to decrease. There would however still be a benefit to band application until soil test P levels were so high that no response at all to P fertilization was obtained.

Studies by Peterson et al (1981) in Nebraska also led to the conclusion that the importance of phosphorus placement diminished as soil P levels increased. Studies of the relationship between fertilizer application rates for winter wheat for broadcast and seed row P showed that the efficiency of broadcast P with respect to seed row placement ranged from 0.3 at low soil test levels to 1.0 at medium soil test levels.

The effect of moisture regime on efficiency of P placement

The benefit to seed row placement or band placement of phosphorus was found by Harapiak and Flore (1984a) to be related to climate. Data from several field studies throughout Alberta showed that under moisture stress, yields of wheat and barley, associated with dual band placement of N and P, were higher than yields obtained with seed row placement. However, under favorable moisture conditions, phosphate placed in the seed row was more effective in increasing yield than dual banded N and P. In Black Chernozemic soils of Manitoba, where annual rainfall is generally high enough to provide adequate moisture for crop production, it would be expected that seed row placement of P would be as, or more, effective than dual bands of N and P.

Recent studies in Alberta by Harapiak and Flore (1985) have shown that split fertilizer P placement, (that is splitting the fertilizer P requirement between the seed row and preplant deep bands), was the most effective P placement for canola. Canola yields of 2270 $kg.ha^{-1}$ were obtained by dual banding 22 $kg.ha^{-1}$ P as monocalcium phosphate with 120 $kg.ha^{-1}$ N. But when 9 $kg.ha^{-1}$ P was dual banded and the remaining 13 $kg.ha^{-1}$ was placed with the seed (totalling 22 $kg.ha^{-1}$), yields of 2450 $kg.ha^{-1}$ were obtained. Seed row placement of monocalcium phosphate at rates greater than 13 $kg.ha^{-1}$ P, resulted in yield depression. Although this study involved the use of monocalcium phosphate rather than monoammonium phosphate, the more commonly used P source in the Prairies, the same concept is applicable. Split P placement can still be a highly effective method of increasing canola yields, but where seed placed MCP was recommended at rates of 13 $kg.ha^{-1}$, the tolerance level to MAP is somewhat lower at about 9 $kg.ha^{-1}$ (Harapiak and Flore, 1985).

The relationship between soil P status and response to placement has also been found to be affected by moisture conditions (Harapiak and Flore, 1984b). Phosphorus placed in the seed row gave a 200 $kg.ha^{-1}$ yield advantage of barley over band placement under favorable moisture conditions on soils which tested low in available P. However, on soils with a medium soil test P level, dual bands resulted in a 240 $kg.ha^{-1}$ yield advantage over seed row placement. This reinforced the concept that importance of P placement diminishes as soil P level increases. In drier areas, with less than optimal available moisture, there was poor correlation between seed row P placement and soil test P levels.

Effect of N carrier on fertilizer P uptake

Many researchers have studied the efficiency of banded phosphate fertilizers, and noted that fertilizer P utilization was stimulated by the application of fertilizer N. Field and greenhouse studies conducted in Nebraska by Olson and Drier (1956) showed that N, in the ammonium form, applied together with P, had a great impact on increasing fertilizer P uptake.

Dion et al (1949a) evaluated the availability of various phosphate carriers to wheat on neutral to alkaline soils and found ammonium phosphate, as a source of P, to be superior to calcium phosphate. Further studies were conducted to determine whether the superiority of ammonium phosphate was due to the nutritive value of the nitrogen component. The availability to wheat of five phosphate carriers, compared at equal application rates of P was as follows: dicalcium phosphate < dicalcium phosphate plus calcium nitrate < monocalcium phosphate < monosodium phosphate < monoammonium phosphate. The N content of the fertilizer did not change the amount of P the plant recovered. The differences in availability of phosphate in these carriers implied that ammonium phosphate is superior to calcium phosphate under neutral to alkaline soil conditions because it remained available longer. This was supported by Rennie and Mitchell (1954) in studies conducted in Saskatchewan with wheat on neutral to alkaline Chernozemic soils, using monocalcium phosphate and monoammonium phosphate.

A marked increase in P utilization by wheat when N, in the ammonium form, was mixed with either MAP or monocalcium phosphate was found by Rennie and Soper (1958) in work conducted in Saskatchewan. The N and P fertilizers must be intimately associated for the increase to occur, and the stimulative effect occurred at an early stage of crop growth. They suggested that increased P uptake (utilization) occurred because the ammonium ion somehow influenced the plant's ability to take up P, and not because the ammonium ion altered the availability of applied P, as concluded by Dion et al (1949a) and Rennie and Mitchell (1954).

Miller and Ohlrogge (1958) in Indiana observed that when ammonium N was dual banded with P, the percent P derived from fertilizer in the band in corn plants increased over all soil levels of phosphate. This indicated that nitrogen influenced the plant's ability to absorb P by causing an increase in the feeding power of the roots on banded phosphorus. Further studies showed that N as $(NH_4)_2SO_4$ enhanced root proliferation in areas of high P concentration (Miller, 1965). The increased root growth alone partially accounted for increased fertilizer P utilization, but as concluded by Miller, "The most probable explanation for the increased P absorption is that $(NH_4)_2SO_4$ exerted a specific influence on the physiological activity that controls P absorption".

A growth chamber study with corn by Leonce and Miller (1966) then led to the conclusion that the NH_4^+ ion increased the transfer of P from the root to the plant top, apparently by increasing the rate at which P moves across the root symplast into the xylem.

The ammonium ion effect was also studied by Miller et al (1970) in a growth chamber study with corn seedlings. Using radioactive labelled monocalcium phosphate either alone, with potassium sulphate, or with ammonium sulphate, it was concluded that an increase in P uptake in the presence of NH_4^+ results from a drop in pH at the root-soil interface.

The exchange of H^+ ions from within the root, for NH_4^+, or K^+ ions, in the soil, accounted for the drop in pH. This is accompanied by decreased precipitation of $CaH_2PO_4.2H_2O$ at the root surface and an increased proportion of P in the $H_2PO_4^-$ form leading to greater P uptake. Riley and Barber (1971) supported this theory when their growth chamber studies with soybeans led to the conclusion that NH_4^+ was not affecting P translocation within the plant, but rather that a drop in pH at the root-soil interface was increasing P absorption. They also reinforced the importance of banding NH_4^+ in intimate association with fertilizer P. It was proposed that when N was broadcast and/or incorporated into the soils, NH_4^+ would quickly be converted to NO_3^-. The uptake of NO_3^- by plant roots is associated with a release of OH^- ions by the roots to balance the anion absorption. This can result in a pH increase of up to 2 units in the rhizosphere. As pH increased, P solubility decreased, and P uptake would therefore decrease also. However, banding of ammonium in intimate association with phosphate, as opposed to broadcasting, discouraged the conversion to nitrate. As NH_4^+ is absorbed by the roots, H^+ is released to balance the charge, rhizosphere pH drops, and the liklihood of P precipitation is decreased, rendering P more available for uptake.

Conversely, field observations have also been made which indicate that high rates of nitrogen placed in N-P dual bands can interfere with P uptake (Harapiak and Flore, 1984b). Phosphate recovery by barley was depressed when N as urea at rates in excess of 100 $kg.ha^{-1}$ was dual banded with P_2O_5 at 45 $kg.ha^{-1}$. Interference was reduced by allowing a time period of 20 days between fertilizer application and seeding for some nitrification to occur and NH_3 to disperse. As applied N rates are increased, the necessary waiting period need also be increased.

Thus, the benefits of banding P, particularly in intimate association with ammonium nitrogen, have been well documented. By concentrating fertilizer phosphorus into a band, efficiency of fertilizer P can be greatly improved, and furthermore, changing the P concentration within a band can affect crop yield.

Effect of band concentration on yield

Soybean yields were found to increase as concentration of fertilizer P in a band increased (Bullen et al, 1983). Band size was altered in a growth chamber experiment by incorporating monocalcium phosphate in 100 %, 50 %, 25 %, 12.5 % and 1 % of the total soil volume at rates of 0.1 g, 0.2 g and 0.4 g P per pot. Dry matter yields at all levels of fertilization increased with a decrease in size of the treated band. That is, applying 0.1 g P to 1 % of the soil resulted in a yield increase 62 % higher than applying 0.1 g P to 100 % of the soil. It was felt this was due to increased fertilizer availability as fertilizer concentration increased. However, great variability exists between crops in their ability to utilize P from a concentrated source such as a band.

Effect of crop type on P uptake

Studies conducted in 1957 and earlier in the Netherlands attributed the benefit of banded P over broadcast P to differences in the nature of the root systems of various crops (Prummel, 1957). Prummel postulated that placement is of particular value to crops with a limited root range such as pulse crops and cereals. Crops with a more extensive root system, such as potatoes and beets, exploit the nutrients in the soil more efficiently and show less benefit to concentrating P in a band.

The effect of the nature of root systems on N and P utilization was investigated in a field study using rape, flax and wheat, which each have different root systems (Racz et al, 1965). Wheat has a fine fibrous root system, typical of cereals. Rapeseed has a more extensive fibrous root system than wheat, while flax has a short taproot. Fertility treatments included combinations of 67 $kg.ha^{-1}$ N broadcast as ammonium nitrate and 22 $kg.ha^{-1}$ P drilled with the seed as triple super phosphate. Rapeseed appeared to be the most responsive to fertilization as rape yields were increased by all fertilizer treatments. Wheat responded only to applications of both N and P, while flax yields were reduced as a result of phosphorus fertilization. Total P uptake also varied considerably between crops, with rapeseed showing a rapid uptake early in the growing season, and highest total P uptake. Wheat and flax absorbed similar total amounts of P but much less than rape. Wheat absorbed its total P requirement within 60 days after seeding. Flax absorbed the same amount at a lower rate over a period of approximately 110 days. The higher phosphorus requirement of rape would, in part, explain why rape gives a better response to P than wheat. The response of each crop to added P can be explained on the basis of the rate of utilization and the total amount of the element needed by the crop, as well as other factors such as soil fertility, rainfall, rate of fertilization, and the ability of the plant to use fertilizer.

Kalra and Soper (1968) studied P absorption by rape, oats, soybeans and flax from a band of ^{32}P labelled monopotassium phosphate in a growth chamber experiment on Manitoba soils. The amount of fertilizer P absorbed depended on the age and type of crop. Rapeseed absorbed the largest amount of fertilizer P, and flax the least, but they absorbed similar amounts of soil P. The "A" values, a measure of soil phosphorus absorbed, decreased in the order soybeans, flax, oats, and rape. Explanations for this variability were postulated to be method of fertilizer application, type of phosphate fertilizer used, root concentration in the fertilizer band, and soil phosphorus level. The effect of method of application on P availability and uptake by rape, flax and oats was further evaluated in a greenhouse experiment (Soper and Kalra, 1969). The size of the reaction zone was changed by either spreading monopotassium phosphate on the soil surface, or adding it in pellet form to a cavity in the center of the pot. They found that mode of application had little effect on yield ($g.pot^{-1}$) of rape, flax or oats. Uptake of P by rape was enhanced by pellet application, but flax and oats uptake of P was decreased as compared to broadcast application. In summary, placing phosphorus in an increasingly concentrated form increased its availability to rape but decreased availability to oats and flax. A second experiment evaluated the availability of monopotassium phosphate, dicalcium phosphate dihydrate and dipotassium phosphate to buckwheat, rape, flax and oats. Buckwheat absorbed a large percentage of added P from all carriers. Rapeseed behaved similarly, but absorbed less total P. Oats absorbed much less P than rape or buckwheat but more than flax. Yield of crops was not affected by P carrier except for oats, where dicalcium phosphate dihydrate resulted in significantly lower yields than when fertilized with the other carriers. Dicalcium phosphate dihydrate appeared to be the least efficient source of P.

Strong and Soper (1973) studied fertilizer reaction zone root development and P absorption efficiency of rape, buckwheat, flax and wheat. Rape and buckwheat utilized a large proportion of KH_2PO_4 (MKP) and K_2HPO_4 (DKP) added as a point source to the center of pot, whereas flax and wheat utilized only a small proportion. Root patterns of flax and buckwheat were not influenced by P application, but root profileration of rape and wheat was enhanced in the reaction zone of MKP. Efficient P utilization by rape was attributed to extensive root proliferation in the reaction zone. Buckwheat's efficiency in using fertilizer P was due to the high absorption capacity of its root system. Flax and wheat did not seem capable of efficient P utilization from a concentrated source. Further studies by Strong and Soper (1974a) quantified root development of these 4 crops in the fertilizer reaction zone. In increasing order, root proliferation of the crops ranked as follows: flax, wheat, buckwheat and rape. The influence of this increased root development on applied P utilization was then assessed. It was concluded that applied P recovery by flax and wheat was related to the proportion of the root system feeding within the reaction zone, and enhanced recovery by rape and buckwheat was related to the advantageous nature of the root system when given the opportunity to absorb P. Rape and buckwheat can recover applied P rapidly due to a major adjustment in root performance (Strong and Soper 1974b). Minor adjustments, as in the case of wheat and flax, result in much slower P recovery. The importance of root adjustment is related to soil P level. Maximum adjustment occurs at low soil P levels, and plays an important role in recovering band applied P.

3. Material and Methods

3.1 Introduction

Analytical procedures for all field and pot studies are described in this section. Field procedures, material and methods applicable to each individual study are described in the appropriate section.

3.2 Plant Tissue Analysis

Sample Preparation. Plant samples for chemical analysis were prepared in the same manner for all studies. Total above ground plant material was harvested at the desired growth stage. Tissue harvested at midseason was oven dried at 50°C, weighed and ground to pass a 2 mm sieve. At final harvest, grain and straw were air dried, threshed, and grain was weighed. Straw weight was determined by difference. In some studies, grain or straw samples were bulked by treatment for chemical analysis.

Phosphorus. Phosphorus was determined as described by Stainton et al (1974). A 1.0 g sample of ground plant material was digested using a nitric-perchloric digestion. The resulting digest was diluted to either 25 ml or 100 ml, for pot experiment or field experiment analysis, respectively. A 0.5 ml aliquot was diluted in 10 ml deionized water, and a second dilution followed of 0.5:10 or 2.5:10 for pot and field studies respectively. Two ml of acid-molybdate complexing reagent were added to each sample and 15 minutes allowed for color development. Phosphorus concentration readings were then taken using a spectrophotometer set at a wavelength of 885 nm. A standard phosphate curve was obtained using phosphate solutions ranging from 0.1 to 10 ppm P. Percent P in plant was then calculated from calibration of standard curve and dilution factor.

Phosphorus derived from fertilizer (Pdff). Total Pdff was determined only on plant material from pot experiments. Material was prepared and digested as for phosphorus determination. The 25 ml diluted digest was centrifuged, and a 15 ml aliquot placed into a scintillation vial. Radioactivity was counted on a Beckman LS 7500 liquid scintillation counter. Standards were prepared by diluting 0.2 ml of the original solutions to 15 ml with distilled water. Background counts were taken and subtracted from each sample. Percent phosphorus derived from fertilizer (% Pdff) was calculated as follows:

$$\%\ \text{Pdff} = \frac{\text{Specific Activity of } {}^{32}\text{P in sample}}{\text{Specific Activity of } {}^{32}\text{P in standard}} \times 100$$

Percent phosphorus derived from fertilizer multiplied by total P uptake (mg) equals total P derived from fertilizer.

Nitrogen. Total nitrogen content was determined by a modified Kjeldahl-Gunning method as described by Jackson (1958). A 0.5 g tissue sample was digested in 5 ml sulfuric acid with 1 Kjeltab containing 3.5 g K_2SO_4 and .0035 g Se at 440°C for approximately 1 hour. The digest was diluted in 25 ml deionized water and titrated with 0.1N H_2SO_4 using a Tecator Kjeltec Auto 1030 Analyzer.

Potassium. Potassium was determined by digesting a 1.0 g sample in a nitric-perchloric digestion, as for phosphorus. A 1.0 ml aliquot of each digest sample was diluted with 2.0 ml of a 2500 ppm $LiNO_3$ solution and 8.5 ml of deionized water. The K concentration was then determined on the filtrate using a Perkin-Elmer 560 Atomic Absorption Spectrophotometer.

3.3 Soil Analysis

Soil Nitrate-Nitrogen. All soil samples were air dried and ground to pass a 2 mm sieve prior to analysis. Soil NO_3-N was determined by the method commonly used by the Manitoba Provincial Soil Testing Laboratory by shaking 2.5 g soil with 50 ml $NaHCO_3$ solution, and 1 g charcoal for 30 minutes. Soil extract was filtered and nitrate plus nitrite-nitrogen was determined by hydrazine reduction using a modification of the automated colorimetric procedure of Kamphake et al. (1967).

Phosphorus. Sodium bicarbonate extractable phosphorus was determined by shaking 2.5 g soil with 50 ml $NaHCO_3$ solution an 1 g charcoal for 30 minutes. Soil extract was filtered and $NaHCO_3$ extractable P was determined on the filtrate using the acid molybdate method of Murphy and Riley (1962).

Potassium. Exchangeable K was determined by extracting 2.5 g soil in 25 ml 1N NH_4OAc. Samples were filtered and K concentration determined on the filtrate by flame photometry using lithium as an internal standard.

Sulphate-Sulphur. Water soluble sulphate-sulphur was determined by extracting 25 g soil with 50 ml of .001 M $CaCl_2$ solution for 30 minutes. The extract was passed through a cation exchange resin and reacted with $BaCl_2$ to form $BaSO_4$ at a pH of 2.5 to 3.0. The excess $BaCl_2$ was reacted with methylthymol blue to form a blue colored chelate at a pH of 12.5 to 13.0. Since the $BaCl_2$ and the methylthymol blue are equimolar, the amount of uncomplexed methylthymol blue is equal to the amount of sulphate present and this was determined colorimetrically on an Auto Analyzer II system as described by Lazrus et al (1966).

Soil pH. A soil-water paste was made using approximately 50 g soil equilibrated with an equal part of water for 30 minutes. Soil pH was then determined using a standard glass-calomel pH electrode.

Electical Conductivity. Conductivity was determined on the same paste used for pH determination by dipping a standard conductivity cell into the mixture.

Moisture content at field capacity. Field capacity was determined by filling a plastic cylinder with 100 g soil and adding water to the soil surface until the wetting front moved one-third to one-half down the cylinder. The cylinder was sealed with parafilm. At 24, 48, and 96 hours, samples were taken from the center of the wetted soil, weighed and oven dried. The oven dry soil was weighed and field capacity was calculated on an oven dry basis.

Calcium Carbonate Equivalent. Calcium carbonate equivalent (%) was determined by a modified procedure of Skinner et al (1959) in a closed system under constant volume and temperature. Soil was reacted with 30 ml 4N HCl in a constant temperature water bath at 25°C. The mixture was shaken and CO_2 given off measured at regular intervals by changes in pressure measured by a manometer. Calcium carbonate equivalent was then calculated from the theoretical values of 43.9 % CO_2 in calcite and 47.73 % CO_2 in dolomite.

4. Field Study 1

4.1 The Effect of Phosphorus Fertilizer Placement on Yield and Phosphorus Recovery by Barley, Rapeseed and Flax

4.1.1 Introduction

Previous work by researchers in Manitoba has shown that crops vary in degree of response to applied phosphorus and their capacity to recover applied P fertilizer. Efficiency of phosphorus fertilizer is largely dependent on method of application, be it broadcast, placed with the seed or banded, and degree of crop response is related to the nature of the plant root system. This study was initiated to evaluate the effect of phosphorus placement on yield and P recovery by barley, flax and rapeseed (Study 1A). However, other treatments were included to permit evaluation of the effect of fall and spring applied P on yield of barley (Study 1B), as well as the effect of broadcasting high rates of N and P on yield of barley, flax and rapeseed (Study 1C).

4.1.2 Material and Methods 1982

Two plot sites were established in the fall of 1981. One of the sites selected was a Reinfeld Series loam, classified as an Orthic Black (designated Glover). The second site was an Almasippi loamy fine sand, classified as a Gleyed Rego Black (designated Middleton). Characteristics of the soils at these sites are shown in Table 1. The Glover soil was low in extractable NO_3-N and P, while exchangeable K

Table 1. Characteristics of Plot Soils In Study 1

	Plot Site	
Characteristic	Glover	Middleton
Classification	Orthic Black	Gleyed Rego Black (Carbonated)
Series	Reinfeld L	Almasippi LFS
NO_3-N (kg.ha^{-1} to 60 cm depth)	25	61
$NaHCO_3$ extractable P (kg.ha^{-1} to 15 cm depth)	9	38
NH_4OAc exchangeable K (kg.ha^{-1} to 15 cm depth)	236	186
water soluble SO_4-S (kg.ha^{-1} to 60 cm depth)	26	52
pH (in water)	7.8	8.2
$CaCO_3$ equivalent (%)	1.2	medium*
Conductivity (dS.m^{-1} to 15 cm depth)	0.2	0.3

*An estimate of free lime content made on the basis of the degree of effervescence of a soil sample to a 1:3 HCl-water solution as determined by the Manitoba Provincial Soil Testing Laboratory and water-soluble sulphate were categorized as being medium. The Middleton site had high extractable levels of all nutrients except potassium which was low. To ensure that lack of K would not limit growth, potassium was broadcast on the entire plot as 0-0-60 at a rate of 70 $kg.ha^{-1}$ K. Both sites were neutral to slightly basic in pH and were nonsaline. The Glover soil was low in $CaCO_3$ (1.2% $CaCO_3$ equivalent), and the Middleton soil was considered to be medium in carbonates, although $CaCO_3$ was not quantitatively determined.

The experimental design consisted of separate blocks of barley, flax and rapeseed and these were not statistically compared. However fertility treatments within each block were completely randomized, and were replicated six times. Ten fertility treatments were included and different combinations of treatments were statistically analyzed in Studies 1A, B and C (See Appendix 1 for samples of Analysis of Variance Tables). Study 1A included treatments 1, 2, 3, 4 and 5. Study 1B included treatments 3, 9 and 10. Study 1C included treatments 6, 7, 8 and 9 for barley, and treatments 3, 6, 7 and 8 for flax and canola. Each replicate was split in half to facilitate seed row placement of P (Figure 1). Plots were harvested on either the A or B side according to the desired treatment.

Fertilizer was broadcast, banded or placed in the seed row for each crop as shown in Table 2. Dual band placement referred to application of N and P together in a common band placed 12 cm deep prior to seeding. "Wide" dual bands were spaced 40 cm apart (treatment 3), while "narrow" dual bands were spaced 20 cm apart (treatment 4). Split P placement referred to placement of one third of the phosphorus

Figure 1. Sketch of Replicate Layout Used in Study 1

```
       7'              | | | |
    |-----|-----|-----|-|-|-|-----|-----|-----|-----|     Side A
    |-----|-----|-----|-|-|-|-----|-----|-----|-----|    seed rows
    |-----|-----|-----|-|-|-|-----|-----|-----|-----|     with P
    |-----|-----|-----|-|-|-|-----|-----|-----|-----|
25' |     |     |     | | | |     |     |     |     |
    |-----|-----|-----|-|-|-|-----|-----|-----|-----|     Side B
    |-----|-----|-----|-|-|-|-----|-----|-----|-----|    seed rows
    |-----|-----|-----|-|-|-|-----|-----|-----|-----|    without P
    |-----|-----|-----|-|-|-|-----|-----|-----|-----|
                      | | | |
```

Preplant bands ↑; Seed rows →

Table 2. Treatments Applied in Field Study 1

Treatment	N applied (kg.ha^{-1})	P applied (kg.ha^{-1})	K applied[1] (kg.ha^{-1})
1. control	100-band	0	0
2. seed row P	100-band	22-seed row (7)[2]	0
3. dual band (wide)[3]	100-band	22-dual band	0
4. dual band (narrow)[3]	100-band	22-dual band	0
5. split P (wide band)[3]	100-band	7-seed row,15 dual	0
6. dual band + N broadcast[4] + K in band	100-band, 100-broadcast[4]	22-dual band	29 with band
7. dual band + N broadcast[4] + K in band + P broadcast	100-band, 100-broadcast[4]	22-dual band, 220-broadcast	29 with band
8. dual band + N broadcast[4] + K in band + P broadcast + K broadcast	100-band, 100-broadcast[4]	22-dual band, 220-broadcast	29 with band 150-broadcast
9. dual band + N broadcast[4]	100-band, 100-broadcast[4]	22-fall dual band	0
10. spring dual band + N broadcast[4]	100-band, 100-broadcast[4]	22-spring dual band	0

N applied as urea (46-0-0)
P applied as monoammonium phosphate (11-55-0)
K applied as KCl (0-0-60)
All bands fall applied and spaced 40 cm apart (wide) unless otherwise indicated
All broadcast N applications spring applied

[1] Prior to treatment application, the Middleton location received 70 kg.ha^{-1} K as 0-0-60

[2] Lower rate applied to flax and canola plots

[3] Wide bands placed 40 cm apart; narrow bands placed 20 cm apart; split placement = 7 kg.ha^{-1} placed in the seed row and 15 kg.ha^{-1} banded

[4] Not applied to flax or canola plots

requirement in the seed row and the remaining two thirds in a dual band with nitrogen (treatment 5). Spring broadcast fertilizer was incorporated with one shallow disc operation. Nitrogen was applied as urea (46-0-0) at 100 $kg.ha^{-1}$ N for placement studies and 200 $kg.ha^{-1}$ N for yield studies. Band and seed row P was applied as monoammonium phosphate (11-55-0) at 7 $kg.ha^{-1}$ to flax and rapeseed, and 22 $kg.ha^{-1}$ P to barley. Broadcast P was applied as triple super phosphate (0-45-0) at 220 $kg.ha^{-1}$ P. Triple super phosphate was used to avoid adding greater than the desired rate of N on those treatments receiving broadcast phosphorus. Potassium was applied as muriate of potash (0-0-60) at 29 $kg.ha^{-1}$ K (band) and 179 $kg.ha^{-1}$ K (broadcast).

Barley (Hordeum vulgare var Bonanza), rapeseed (Brassica campestris var Torch), and flax (Linum usitatissimum var Dufferin) were seeded at 100, 6, and 40 $kg.ha^{-1}$ respectively. Plots were seeded perpendicular to fertilizer bands with an 8 run double disc seeder with 7 inch (17.8 cm) row spacing.

At the tillering stage (thirty four days after seeding), a 0.36 m^2 (2 rows x 1.0 m) area of barley was sampled for yield and tissue analysis. Midseason samples were not taken of flax or rapeseed. At maturity, samples were taken for yield and nutrient uptake determination. The area harvested was 1.3 m^2 (8 rows x 0.9 m) for flax and barley and 0.9 m^2 (8 rows x 0.6 m) for canola.

Recommended herbicides were applied to the barley and rapeseed blocks for weed control. Flax at the Middleton site was not harvested due to poor growth and a severe infestation of wild oats, green foxtail, Russian thistle and lamb's quarters, which were not controlled by two applications of Poast herbicide.

Samples were air dried and analyzed as outlined in Section 3.2.

4.1.3 Material and Methods 1983

The Middleton site was discontinued after the 1982 field season due to lack of significant response to applied P at final harvest. Fertility treatments were reapplied as in 1982 at the Glover site. Methods were consistent with those used in 1982 except that canola (Brassica napus var Regent) was planted instead of rapeseed (Brassica campestris var Torch); and above ground dry matter samples were taken 31 and 46 days after planting of barley and flax, respectively. The area harvested was 0.3 m^2 (2 rows x 0.8 m). At maturity, final harvests were taken for yield and nutrient content from a 1.2 m^2 (8 rows x 0.8 m) area. The canola plot suffered from poor emergence, possibly due to moisture deficient topsoil, and a problem with flea beetles. Consequently it was worked down prior to midseason harvest.

4.2 Results and Dicussion

4.2.1 The Effect of Phosphorus Placement (Study 1A)

The effect of phosphorus placement on yield and nutrient uptake by barley, rapeseed and flax was evaluated by comparing seedrow, wide dual bands, narrow dual bands and split applications of P (treatments 2, 3, 4, and 5) with the control (treatment 1).

In 1982, soil moisture content at seeding was not quantitively determined, but was sufficient for good germination. Early season precipitation was below average to average (Environment Canada, 1982) resulting in spotty growth. However, rainfall was plentiful in July, and earlier problems were overcome. This resulted in a healthy crop stand by final harvest. In 1983, adequate precipitation occurred at regular intervals, and the crops showed no signs of moisture stress. However, an extended period of high temperature during the flowering and filling period resulted in grain yields that were low relative to what was anticipated.

4.2.1.1 Barley

Dry matter yields of barley at midseason harvest at the Middleton site in 1982 ranged from 561 $kg.ha^{-1}$ on the control to 843 $kg.ha^{-1}$ where P was placed in the seed row (Table 3). This was a significant effect due to treatment. Narrow dual bands produced 770 $kg.ha^{-1}$ which was also significantly greater than the control. Wide dual bands and split P treatments increased yield compared to the control, but differences were not significant. In 1982 the Glover site produced dry matter yields which ranged from 370 $kg.ha^{-1}$ on the control to 629 $kg.ha^{-1}$ where P was placed with the seed. Seed row P and narrow dual bands increased dry matter yield significantly over the control. Wide dual bands and split P placements increased yield compared to the control, but not significantly. All placements in 1983 gave significant yield increases compared to the control with the largest yield increase of 419 $kg.ha^{-1}$ associated with split phosphorus application (treatment 5). Yields of wide and narrow dual bands were

Table 3. Midseason Dry Matter Production of Barley in Study 1A ($kg.ha^{-1}$)

	Location and Year		
Treatment	Middleton 1982	Glover 1982	Glover 1983
1. control (0P)	561 c	370 b	357 c
2. seed row P	843 a	629 a	629 b
3. dual band (wide)	614 bc	518 ab	608 b
4. dual band (narrow)	770 ab	528 a	622 b
5. split P	719 abc	505 ab	776 a

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Rate of fertilization = 100 $kg.ha^{-1}$ N as urea, 22 $kg.ha^{-1}$ P as MAP

Wide dual bands placed 40 cm apart; narrow dual bands placed 20 cm apart; split P = 7 $kg.ha^{-1}$ with the seed and 15 $kg.ha^{-1}$ P banded

All bands fall applied

Table 4. Midseason Nitrogen Uptake ($kg.ha^{-1}$) and Concentration (%) in Barley in Study 1A

	Location and Year					
Treatment	Middleton 1982		Glover 1982		Glover 1983	
	uptake	%	uptake	%	uptake	%
1. control (0P)	25.1 c	4.47	16.9 b	4.56	18.4 c	5.15
2. seed row P	41.3 a	4.90	27.3 a	4.34	30.3 b	4.82
3. dual (wide)	28.6 bc	4.66	24.1 a	4.65	32.1 b	5.27
4. dual (narrow)	34.6 ab	4.49	22.8 a	4.32	33.7 b	5.42
5. split P	32.5 abc	4.52	23.6 a	4.67	41.7 a	5.37

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Rate of fertilization = 100 $kg.ha^{-1}$ N, 22 $kg.ha^{-1}$ P

similar to seed row placement, all of which were superior to the control, but inferior to split P placement.

Dry matter yields at midseason harvest at the Middleton site were substantially higher for most treatments than at Glover's in either test year. This could be attributed to the higher initial fertility status of the Middleton site (Table 1). An overall view of treatment performance showed that seed row P and narrow dual band placement (treatments 2 and 4) resulted in higher yields than other treatments in 1982. However, in 1983, split P application was more effective in increasing yield than the other treatments.

Nitrogen uptake at the Middleton site was increased significantly compared to the control by treatments 2 and 4, and corresponded to yield increases (Table 4). Percent N ranged from 4.47 % in the control to 4.90% with seed row P. In 1982 at the Glover site, N uptake was significantly increased compared to the control by all methods of placement, but differences between treatments where P was applied were not significant. Nitrogen concentration was similar among all treatments and no treatment effect was noted. In 1983, N uptake was significantly increased compared to the control by all methods of P application. Split P application resulted in significantly higher uptake than either dual band placement and seed row placement. Percent N was lowest when P was placed in the seed row at 4.82 %, and increased to 5.42 % with narrow dual band placement. Variation in N concentration was likely not due to treatment, as all treatments were fertilized with 100 $kg.ha^{-1}$ N banded.

Total P uptake at midseason harvest at Middleton's was significantly increased compared to the control as a result of P fertilization except with wide dual band placement (Table 5).

Phosphorus concentration was significantly increased compared to the control when P was placed in the seed row or split between the seed row and the N-P dual band. At Glover's in 1982, P uptake was doubled with any method of P application compared to the control. Phosphorus concentration increased significantly from 0.27 % in the control to 0.39 % to 0.40 % for fertility treatments. Similarly, in 1983, P uptake and concentration increased from 0.95 $kg.ha^{-1}$ (0.27 %) in the control to 3.7 $kg.ha^{-1}$ (0.48 %) with split P application. Thus the application of P did increase barley P uptake but method of P application was of little consequence.

Final grain yields in 1982 at Middleton's ranged from 3595 to 4198 $kg.ha^{-1}$ (Table 6) and were considered to be average to excellent when compared to the 1982 average regional production of 3431 $kg.ha^{-1}$ (Manitoba Agriculture Yearbook, 1983). Significant response to P fertilization at the Middleton site was not apparent despite midseason effects. However, P applied in the seed row and dual band placements did increase yield by up to 600 $kg.ha^{-1}$ as compared to the control. The lack of significant yield increases at the Middleton site might be explained by considerable field variation. Analysis of variance showed significant differences between replicates and a coefficient of variation of 19.9 (Appendix 1). In 1982 at the Glover site, significant yield response of barley to applied P was obtained. Seed yields were significantly increased by P added in the seed row, split P placement, and wide dual bands. Narrow dual bands, a superior

Table 5. Midseason Phosphorus Uptake ($kg.ha^{-1}$) and Concentration (%) in Barley in Study 1A

Treatment	Middleton 1982 uptake	Middleton 1982 %	Glover 1982 uptake	Glover 1982 %	Glover 1983 uptake	Glover 1983 %
1. control (OP)	2.3 c	0.41 b	1.0 b	0.27 b	0.95 c	0.27 b
2. seed row P	3.9 a	0.46 a	2.5 a	0.40 a	2.9 b	0.46 a
3. dual (wide)	2.6 bc	0.42 b	2.0 a	0.39 a	2.8 b	0.46 a
4. dual (narrow)	3.3 ab	0.43 ab	2.1 a	0.40 a	2.7 b	0.43 a
5. split P	3.3 ab	0.46 a	2.0 a	0.40 a	3.7 a	0.48 a

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Rate of fertilization = 100 $kg.ha^{-1}$ N, 22 $kg.ha^{-1}$ P

Table 6. Yield of Barley at Maturity in Study 1A ($kg.ha^{-1}$)

Treatment	Middleton 1982 grain	Glover 1982 grain	Glover 1983 grain
1. control (OP)	3595	3668 b	2732 b
2. seed row P	4198	4399 a	3294 ab
3. dual (wide)	4078	4278 a	3149 ab
4. dual (narrow)	4097	4074 ab	2869 ab
5. split P	3670	4284 a	3513 a
	NS		

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Rate of fertilization = 100 $kg.ha^{-1}$ N, 22 $kg.ha^{-1}$ P

treatment at midseason, did not significantly increase final grain yield above the control. Grain yields in 1983 were significantly increased compared to the control only with split P application. Seed row P and dual band placements produced yields greater than the control, but increases were not significantly different from the control, despite midseason effects. The results from 1983 are consistent with findings by Harapiak and Flore (1984a). Dryland studies of wheat and barley led to the conclusion that the benefit of a split P application over dual bands is greater under favorable moisture conditions than under moisture stress. This concept is applicable to the findings of this study as moisture conditions throughout the growing season in 1983 were generally favorable, resulting in greater yield with split P placement (3515 $kg.ha^{-1}$) compared to dual band placements (3149 $kg.ha^{-1}$ with wide bands and 2869 $kg.ha^{-1}$ with narrow bands).

Statistical analysis could not be conducted on uptake data of final harvest in 1982, due to bulking of samples by treatment prior to analysis. Nitrogen uptake by the grain at Middleton's ranged from 75.6 to 90.9 $kg.ha^{-1}$ and percent N ranged from 1.80 to 2.43 % (Table 7). Both N uptake and concentration were lowest in the seed row P treatment, but there is no obvious reason for this. At Glover's in 1982, N uptake increased with P application for all treatments and was greatest with seed row P. Percent N was lowest at 1.69 % in the control and increased with P fertilization to 2.02 % with split P application. In 1983, N uptake increased significantly with split P placement compared to the control and narrow dual bands. Seed row P,

Table 7. Nitrogen Uptake ($kg.ha^{-1}$) and Concentration (%) in Barley at Maturity in Study 1A

Treatment	Middleton 1982 uptake	Middleton 1982 %	Glover 1982 uptake	Glover 1982 %	Glover 1983 uptake	Glover 1983 %
1. control (0P)	87.4	2.43	62.0	1.69	59.9 b	2.19
2. seed row P	75.6	1.80	87.1	1.98	68.0 ab	2.05
3. dual (wide)	90.9	2.23	76.6	1.79	67.7 ab	2.13
4. dual (narrow)	83.6	2.04	73.3	1.80	59.2 b	2.05
5. split P	82.6	2.25	86.5	2.02	79.0 a	2.25

Location and Year

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Rate of fertilization = 100 $kg.ha^{-1}$ N, 22 $kg.ha^{-1}$ P

Table 8. Phosphorus Uptake ($kg.ha^{-1}$) and Concentration (%) in Barley at Maturity in Study 1A

Treatment	Middleton 1982 uptake	Middleton 1982 %	Glover 1982 uptake	Glover 1982 %	Glover 1983 uptake	Glover 1983 %
1. control (0P)	7.9	0.22	12.5	0.34	9.2 b	0.34 b
2. seed row P	13.4	0.32	17.2	0.39	12.7 a	0.39 a
3. dual (wide)	8.6	0.21	16.3	0.38	12.5 a	0.40 a
4. dual (narrow)	11.9	0.29	12.6	0.31	11.8 a	0.41 a
5. split P	8.1	0.22	15.4	0.36	13.7 a	0.39 a

Location and Year

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Rate of fertilization = 100 $kg.ha^{-1}$ N, 22 $kg.ha^{-1}$ P

wide dual bands and narrow dual bands did not differ significantly from the control. Percent N was similar among treatments and was highestwith split P placement.

Phosphorus uptake in the grain was greater than the control when P was applied by any method at all sites (Table 8). At Middleton's, P uptake and percent P was highest with seed row placement, followed by narrow dual bands. Uptake with wide dual bands and split placements were only slightly higher than the control, and percent P was equal to the control. In 1982 at Glover's, P uptake increases were large with all methods of P placement except narrow dual bands. Variation in uptake was consistent with variation in yield, but with respect to narrow dual bands, percent P was slightly lower than the control. In 1983, P uptake and % P were increased significantly compared to the control by all methods of placement but differences were not significant between treatments where P was applied.

4.2.1.2 Rapeseed

Rapeseed was harvested at maturity for yield and tissue analysis at Middleton's and Glover's in 1982 (Table 9). Grain yields at Middleton's ranged from 925 to 1163 kg.ha^{-1}, slightly lower than the 1982 average regional production of 1235 kg.ha^{-1} (Manitoba Agriculture Yearbook, 1983). While there was no significant response to P application, seed row P (treatment 2), narrow dual bands (treatment 4) and split P (treatment 5) applications produced yields lower than the control. At Glover's, grain yields were considerably better than at Middleton's and ranged from 1878 kg.ha^{-1} in the control to 2391 kg.ha^{-1}

Table 9. Yield of Rapeseed at Maturity in Study 1A (kg.ha^{-1})

	Location and Year	
Treatment	Middleton 1982 grain	Glover 1982 grain
1. control (0P)	1134	1878 b
2. seed row P	1080	2102 b
3. dual (wide)	1163	2049 b
4. dual (narrow)	1111	2391 a
5. split P	925	2074 b
	NS	

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Rate of fertilization = 100 kg.ha^{-1} N as urea, 22 kg.ha^{-1} P as MAP (7 kg.ha^{-1} P in seed row)

Wide dual bands placed 40 cm apart; narrow dual bands placed 20 cm apart; split P = 7 kg.ha^{-1} with the seed and 15 kg.ha^{-1} P banded

All bands fall applied

Table 10. Nitrogen and Phosphorus Uptake (kg.ha^{-1}) and Concentration (%) in Rapeseed at Maturity in Study 1A

	Location and Year							
Treatment	Middleton 1982				Glover 1982			
	Nitrogen		Phosphorus		Nitrogen		Phosphorus	
	uptake	%	uptake	%	uptake	%	uptake	%
1. control (0P)	44.6	3.96	8.8	0.78	52.2	2.78	13.7	0.73
2. seed row P	41.9	3.92	7.9	0.73	80.1	3.81	10.7	0.51
3. dual (wide)	44.9	3.39	8.5	0.73	77.7	3.79	12.9	0.63
4. dual (narrow)	41.6	3.80	9.4	0.85	91.6	3.83	18.9	0.79
5. split P	33.9	3.78	6.6	0.73	74.9	3.61	15.3	0.74

Rate of fertilization = 100 kg.ha^{-1} N, 22 kg.ha^{-1} P (7 kg.ha^{-1} P in seed row) with narrow dual bands. Grain yields were increased with phosphorus application by any method compared to the control, but only narrow dualbands (treatment 4) significantly increased yield.

Statistical analysis on N and P uptake data was not possible due to bulking of samples by treatment prior to analysis. Nitrogen uptake in the grain at the Middleton location ranged from 33.9 to 44.9 $kg.ha^{-1}$, following the same pattern as yield (Table 10). Nitrogen concentration was constant among treatments and P fertilization had no effect on N uptake. However at the Glover location, N uptake was increased with the addition of P. Percent N increased from 2.78 % in the control to a range of 3.61 to 3.83 % for other treatments. Perhaps the application of fertilizer P stimulated a better root system, resulting in increased N uptake.

Phosphorus uptake in the grain at Middleton's ranged from 6.6 $kg.ha^{-1}$ with split P application to 9.4 $kg.ha^{-1}$ with narrow dual band placement. Percent P ranged from 0.73 % with split P placement to a high of 0.85 % with narrow dual bands. Only narrow dual bands resulted in higher P uptake than the control. Phosphorus uptake at Glover's was higher than at Middleton's and lowest P uptake and percent P corresponded to seed row P placement (treatment 2). A pronounced increase in P uptake and percent P due to narrow dual band placement was noted at the Glover location, similar to the effect noted at Middleton's.

4.2.1.3 Flax

Midseason samples of flax were harvested only in 1983, 46 days after seeding. Crop emergence was noted to be uneven. While yield varied from 1053 to 1338 $kg.ha^{-1}$, no significant differences were noted due to P placement (Table 11). Seed row placement (treatment 2) resulted in yields lower than the control. The low yield produced by seed row placement was unexpected and perhaps suggested a toxic effect of MAP on the seed. However this is unlikely since treatment 5, which also received 7 $kg.ha^{-1}$ with the seed, yielded well relative to other treatments. Variation in N and P uptake reflected variation in yield, and actual nutrient concentration was very constant regardless of treatment (Table 11). It should be noted that a large visual response to banded P could be seen shortly after crop emergence. The flax plots were seeded perpendicular to the bands and approximately 4 weeks after seeding, enhanced flax growth directly above the bands was very obvious. This supported the findings of Sadler and Bailey (1981) that the most efficient placement of P for flax is band placement directly below the seed. Unfortunately no equipment was available for this study to enable a treatment to be applied in which P was placed directly below the seed. The visual symptoms of crop response to enhanced P utilization had disappeared by midseason harvest, and were not apparent in yield or nutrient uptake data.

Final flax grain yields were increased slightly in response to P fertilization in 1982, although not significantly (Table 12). Grain yields in 1982 ranged from 1478 to 1575 $kg.ha^{-1}$ (averaging 1528 $kg.ha^{-1}$), slightly higher than the 1982 average regional production of 1315 $kg.ha^{-1}$ (Manitoba Agriculture Yearbook, 1983). In 1983 yields were considerably less, with an overall average of 1013 $kg.ha^{-1}$. Only

Table 11. Midseason Dry Matter Production of Flax, Nitrogen and Phosphorus Uptake (kg.ha^{-1}) and Concentration (%) in Flax in Study 1A

Treatment	Location and Year Glover 1983 Yield (kg.ha^{-1})	Nitrogen uptake	Nitrogen %	Phosphorus uptake	Phosphorus %
1. control (0P)	1172	41.9	3.58	3.1	0.26
2. seed row P	1053	38.0	3.61	3.0	0.28
3. dual (wide)	1245	42.8	3.44	3.6	0.29
4. dual (narrow)	1338	46.8	3.50	3.7	0.28
5. split P	1312	45.7	3.48	3.8	0.29
	NS	NS		NS	NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Rate of fertilization = 100 kg.ha^{-1} N as urea, 22 kg.ha^{-1} P as MAP (7 kg.ha^{-1} P in seed row)

Wide dual bands placed 40 cm apart; narrow dual bands placed 20 cm apart; split P = 7 kg.ha^{-1} with the seed and 15 kg.ha^{-1} P banded

All bands fall applied

Table 12. Yield of Flax at Maturity in Study 1A (kg.ha^{-1})

	Location and Year	
Treatment	Glover 1982 grain	Glover 1983 grain
1. control (0P)	1478	1047
2. seed row P	1501	986
3. dual (wide)	1514	985
4. dual (narrow)	1575	1084
5. split P	1571	963
	NS	NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Rate of fertilization = 100 kg.ha^{-1} N, 22 kg.ha^{-1} P (7 kg.ha^{-1} P in seed row)

Table 13. Nitrogen and Phosphorus Uptake (kg.ha^{-1}) and Concentration (%) in Flax at Maturity in Study 1A

	Location and Year							
Treatment	Glover 1982				Glover 1983			
	Nitrogen		Phosphorus		Nitrogen		Phosphorus	
	uptake	%	uptake	%	uptake	%	uptake	%
1. control (0P)	52.7	3.57	7.4	0.50	43.8	4.20	5.1 b	0.49 b
2. seed row P	53.1	3.54	6.9	0.46	39.9	4.05	5.7 ab	0.58 a
3. dual (wide)	53.0	3.50	8.2	0.54	38.6	3.90	6.1 ab	0.62 a
4. dual (narrow)	56.9	3.61	9.5	0.60	43.8	4.04	6.8 a	0.62 a
5. split P	51.2	3.46	9.0	0.57	39.5	4.10	5.7 ab	0.60 a
					NS			

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Rate of fertilization = 100 kg.ha^{-1} N, 22 kg.ha^{-1} P (7 kg.ha^{-1} P in seed row) narrow dual band placement resulted in higher yields than the control. Lack of significant yield response was likely due to the reduced rate of fertilizer P utilization, and lower P requirement of flax, as compared to rape, as suggested by Racz et al (1965).

Statistical analysis was not possible on uptake data in 1982 due to bulking of samples by treatment prior to analysis. Nitrogen uptake and % N were similar among all treatments in 1982. In 1983, N uptake was not significantly affected by any treatment but uptake was lower than the control in all treatments except narrow dual bands. Percent N was highest in the control.

Phosphorus uptake in 1982 was increased by all methods of P placement compared to the control except for seed row placement (treatment 2) (Table 13). Percent P in 1982 was increased up to 0.60 % with P fertilization compared to the control (0.50 %) except for treatment 2, in which P content was decreased to 0.46 %. In 1983, P uptake was significantly increased compared to the control with the narrow dual banded treatment. Percent P was significantly increased compared to the control by all methods of P placement. The increased uptake of P associated with band placements compared to seed row placement, although not significant, support the theory of Sadler and Bailey (1981) that P placement below the seed is the most efficient placement of fertilizer P for flax.

4.2.1.4 Summary

In summary, while few significant yields responses were obtained to P fertilization by any crop, barley yields were generally increased with the application of fertilizer phosphorus. In 1982, when June moisture reserves were limited, seed row placement of P was most effective in increasing dry matter production of barley early in the season. By final harvest, little difference due to placement was apparent. In 1983, under favorable moisture conditions, split P application was most effective in increasing barley grain yields. Seed row placement and dual band placements performed equally well, and yields were not significantly different from either the control, or split P placement. These findings support research by Flaten and Racz (1984) in which wheat yields were similar whether P was applied in the seed row, dual banded at either 18 or 36 cm spacings with N, or placed in separate bands of N and P. Increases in P concentration with P fertilization generally accompanied increases in yield, but uptake data was variable and inconclusive. Rapeseed responded most favorably to narrow dual band placement of N and P, but only at one site. Phosphorus uptake data was again variable, but N concentration in the grain was increased with P fertilization by any method. This is in contrast to barley, in which N concentration was unaffected by the addition of P by any method. Flax yields were not significantly affected by P fertilization. However, narrow dual bands produced the highest yield in both years. Nitrogen uptake by flax was not increased with P fertilization, although P uptake and concentration increased with P fertilization.

4.2.2 The Effect of High Rate of N Applied Broadcast and Spring versus Fall Banded N on Barley (Study 1B)

In addition to evaluating the relative effectiveness of broadcast, seed placed, and banded P, Study 1 allowed for a concurrent evaluation of spring broadcast N with fall or spring placed bands. These treatments were applied only to barley.

Treatments used in this comparison are treatments 3, 9 and 10 (Table 2). Treatment 3 consisted of a fall applied wide (40 cm) dual band placement of 100 $kg.ha^{-1}$ N and 22 $kg.ha^{-1}$ P. Treatment 9 consisted of 100 $kg.ha^{-1}$ N spring broadcast in addition to a fall applied wide dual band (100 $kg.ha^{-1}$ N, 22 $kg.ha^{-1}$ P). An evaluation of the effect of high rate broadcast N on barley yield was made by comparing treatments 3 and 9. Treatment 10 consisted of 100 $kg.ha^{-1}$ N spring broadcast in addition to a spring applied wide dual band (100 $kg.ha^{-1}$ N, 22 $kg.ha^{-1}$ P). A comparison of treatments 9 and 10 allowed for an evaluation of spring versus fall applied bands.

The application of 100 $kg.ha^{-1}$ N spring broadcast and incorporated prior to seeding in addition to an N-P fall applied dual band (treatment 9) significantly decreased yields as compared to a dual band alone (treatment 3) at the Middleton site in 1982 (Table 14). Plots receiving 100 $kg.ha^{-1}$ N broadcast were slow to emerge and growth was not uniform. At the Glover location in both 1982 and 1983, barley dry matter production was also reduced with broadcast N compared to dual bands alone, but differences were not significant. Yield of spring dual bands plus broadcast N (treatment 10) were slightly higher than

Table 14. Midseason Dry Matter Production of Barley in Study 1B (kg.ha^{-1})

	Location and Year		
Treatment	Middleton 1982	Glover 1982	Glover 1983
3. fall dual band	614 a	518 a	608 a
9. fall dual band + 100 N broadcast	445 b	446 ab	582 a
10. spring dual band + 100 N broadcast	538 ab	314 b	348 b

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Dual band = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P; All band spacing = 40 cm; Broadcast N was spring applied

Table 15. Midseason Nitrogen Uptake (kg.ha^{-1}) and Concentration (%) in Barley in Study 1B

	Location and Year					
Treatment	Middleton 1982		Glover 1982		Glover 1983	
	uptake	%	uptake	%	uptake	%
3. fall dual band	28.6	4.66	24.1 a	4.65	32.1 a	5.28
9. fall dual band + 100 N broadcast	24.3	5.46	23.1 ab	5.18	30.7 a	5.27
10. spring dual band + 100 N broadcast	27.6	5.13	16.3 b	5.19	19.5 b	5.60
	NS					

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Dual band = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P; All band spacing = 40 cm; Broadcast N was spring applied

fall dual bands plus broadcast N at Middleton's in 1982. However at Glover's in 1982, fall dual bands plus broadcast N resulted in higher yields than treatment 10 but differences were not significant. In 1983, fall dual bands produced significantly greater dry matter than spring dual bands.

While nitrogen uptake at midseason at all sites was less with the application of broadcast N than dual bands alone (treatment 3), N concentration was increased or unchanged (Table 15). At Middleton's in 1982, fall bands resulted in 4.66 % plant N and was increased to 5.46 % N when rate of N applied was increased to 200 kg.ha^{-1}. Similar increases occurred at Glover's in 1982. Timing of band application had little effect on N uptake at Middleton's. Spring applied bands resulted in reduced N uptake at Glover's in 1982, compared to fall bands, but % N was unaffected. In 1983, while N uptake was significantly reduced with spring bands compared to fall bands, % N was slightly increased when bands were spring applied as compared to fall applied.

Phosphorus uptake at midseason harvest at Middleton's was significantly decreased with the application of broadcast N compared to dual bands alone, but % P in the plant was not significantly changed (Table 16). In 1982 at Glover's, percent P was not significantly different between treatments 3 and 9, thus increased rate of N application did not affect P uptake. In 1983, % P was significantly reduced with broadcast N compared to dual bands alone. Timing of band placement did not affect P uptake at Middleton's. Broadcast N with spring applied dual bands significantly reduced both P uptake and

Table 16. Midseason Phosphorus Uptake (kg.ha^{-1}) and Concentration (%) in Barley in Study 1B

	Location and Year					
Treatment	Middleton 1982		Glover 1982		Glover 1983	
	uptake	%	uptake	%	uptake	%
3. fall dual band	2.6 a	0.42	2.0 a	0.39 a	2.8 a	0.46 a
9. fall dual band + 100 N broadcast	1.9 b	0.43	1.7 a	0.38 a	2.4 a	0.41 b
10. spring dual band + 100 N broadcast	2.3 ab	0.43	1.0 b	0.32 b	1.1 b	0.32 c
		NS				

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Dual band = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P; All band spacing = 40 cm; Broadcast N was spring applied

Table 17. Yield of Barley at Maturity in Study 1B (kg.ha^{-1})

	Location and Year		
Treatment	Middleton 1982	Glover 1982	Glover 1983
	grain	grain	grain
3. fall dual band	4078 a	4278	3149
9. fall dual band + 100 N broadcast	3090 b	4107	3479
10. spring dual band + 100 N broadcast	3249 b	4634	3180
		NS	NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Dual band = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P; All band spacing = 40 cm; Broadcast N was spring applied

% P at the Glover site in both 1982 and 1983 in comparison to fall placed bands plus broadcast N. The decreased uptake of P associated with spring applied dual bands might be due to the presence of free NH_3 from urea inhibiting plant roots from entering the band and contacting P (Flaten and Racz, 1985).

At maturity, yield was reduced by 24 % when 100 $kg.ha^{-1}$ N was broadcast in addition to fall applied dual N-P bands compared to fall N-P dual bands alone at Middleton's (Table 17). This difference was not significant. At Glover's, while no significant response to added N was obtained in either year, high rate broadcast N in addition to fall applied dual bands did increase yield by 330 $kg.ha^{-1}$ in 1983 compared to fall applied dual bands alone. An evaluation of spring bands plus broadcast N (treatment 10) and fall bands plus broadcast N (treatment 9) also showed no significant effect of timing of band application on yield. Spring bands were superior to fall bands in increasing barley yield in 1982, but inferior in 1983. The lack of significant difference between fall and spring bands is in contrast to midseason data, where fall bands produced dry matter yields significantly greater than spring applied fertilizer in 1983. The results from 1983 conflict with reports by Nyborg and Malhi (1982) that fall applied N was always inferior to spring applied N. This discrepancy may be explained on the basis that the research by Nyborg and Malhi involved the application of broadcast N, which is more subject to over-winter losses than banded N. Also, yield differences resulting from fall vs spring applied nitrogen have been cited to be greater in Northern Alberta than differences found in Manitoba (Nyborg and Malhi (1982). However, the findings of this study support reports by Toews (1982) that fall dual bands of N and P are as effective as spring dual bands in increasing barley yields.

Statistical analysis was not possible on nutrient uptake data of 1982 at maturity due to bulking of samples by treatment prior to analysis. Nitrogen uptake in barley grain was not increased with the application of broadcast N compared to the fall dual band treatment at either site in 1982 (Table 18). Percent N was also similar between treatments 3 and 9. In 1983 nitrogen uptake increased significantly from 67.7 $kg.ha^{-1}$ with dual bands alone to 90.5 $kg.ha^{-1}$ with treatment 9 and N concentration increased 0.48 % with the addition of broadcast N. Effect of timing of N-P band application on N uptake was variable. Nitrogen uptake decreased at Middleton's from 88.7 $kg.ha^{-1}$ with fall bands to 70.1 $kg.ha^{-1}$ with spring bands but % N was similar. In 1982 at Glover's nitrogen uptake increased from 76.6 $kg.ha^{-1}$ with fall bands to 99.6 $kg.ha^{-1}$ with spring, and % N was again similar. In 1983 there was no effect of timing on N uptake or N concentration in barley.

Phosphorus uptake and % P at Middleton's increased dramatically with high rate broadcast N, although yield was decreased significantly (Table 19). The increase in P concentration with the plant with high rate broadcast N accompanied by significantly reduced yields suggested that a sufficient amount of P was available to the crop after fertilization. Yield may have been limited due to a deficiency of another nutrient or less than optimal growing conditions. In 1982 at Glover's, P uptake and % P were not affected by N fertilization. While significantly increased P uptake occurred at Glover's in 1983 with

Table 18. Nitrogen Uptake (kg.ha^{-1}) and Concentration (%) in Barley at Maturity in Study 1B

	Location and Year					
Treatment	Middleton 1982		Glover 1982		Glover 1983	
	uptake	%	uptake	%	uptake	%
3. fall dual band	90.9	2.23	79.3	1.79	67.7 b	2.13
9. fall dual band + 100 N broadcast	88.7	2.42	76.6	1.93	90.5 a	2.61
10. spring dual band + 100 N broadcast	70.1	2.27	99.6	2.15	85.1 a	2.68

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Dual band = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P; All band spacing = 40 cm; Broadcast N was spring applied

Table 19. Phosphorus Uptake (kg.ha^{-1}) and Concentration (%) in Barley at Maturity in Study 1B

	Location and Year					
Treatment	Middleton 1982		Glover 1982		Glover 1983	
	uptake	%	uptake	%	uptake	%
3. fall dual band	8.6	0.21	16.3	0.38	12.5 b	0.40
9. fall dual band + 100 N broadcast	11.7	0.32	15.6	0.38	14.5 a	0.42
10. spring dual band + 100 N broadcast	9.6	0.31	15.8	0.34	11.5 b	0.36
						NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Dual band = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P; All band spacing = 40 cm; Broadcast N was spring applied

broadcast N application, % P was not greatly affected. A comparison of treatments 9 and 10 showed a drop in P uptake with spring bands compared to fall but no change in % P at Middleton's. In 1982 at Glover's, P uptake and % P were not affected by timing of band application. In 1983, P uptake was significantly reduced with spring applied bands plus broadcast N compared to fall applied bands plus broadcast N, but was equal to uptake with fall dual bands alone. Differences in % P were not significant.

An overall view of treatments showed effects of broadcasting 100 $kg.ha-^1$ N in addition to an N-P dual band (100 $kg.ha^{-1}$ N and 22 $kg.ha^{-1}$ P) to be variable. Barley yields and N concentration increased slightly in 1983, and decreased or remained unchanged in 1982 when 100 $kg.ha^{-1}$ N was broadcast. Percent P was increased at Middleton's but was unaffected at Glover's by the same treatment. Timing of band placement had no significant effect on barley yield or nutrient uptake, although % P tended to decrease with spring band applications.

4.2.3 Application of Nitrogen, Phosphorus and Potassium for High Yields (Study 1C)

Study 1A evaluated the effect of P placement on barley, rapeseed and flax yield and nutrient uptake, using constant rates of P and N. In Study 1C application rates were increased in an attempt to evaluate the effect of application of high rates of N, P and K on barley, rapeseed and flax yields.

Treatments used in this comparison were treatments 6, 7, 8 and 9 (Table 2) for barley. Treatment 9 included a dual N-P band (100 $kg.ha^{-1}$ N and 22 $kg.ha^{-1}$ P) plus 100 $kg.ha^{-1}$ N broadcast in the spring (designated basal). Other treatments were as follows: treatment 6 included basal treatment plus 29 $kg.ha^{-1}$ K in a triple band; treatment 7 included basal treatment plus 29 $kg.ha^{-1}$ banded K plus broadcast 220 $kg.ha^{-1}$ P; and treatment 8 included basal treatment plus 29 $kg.ha^{-1}$ banded K plus 220 $kg.ha^{-1}$ P broadcast plus 150 $kg.ha^{-1}$ K broadcast. This resulted in 4 treatments where applied rates of N, P and K were increased to a maximum of 200 $kg.ha^{-1}$ N, 242 $kg.ha^{-1}$ P, and 179 $kg.ha^{-1}$ K.

For flax and rapeseed, treatments 3, 6, 7 and 8 were compared. Treatment 3 consisted of an N-P dual band at rates of 100 $kg.ha^{-1}$ N and 22 $kg.ha^{-1}$ P (designated basal). Treatments 6, 7 and 8 were as described above, except that no broadcast N was included. This series of treatments resulted in a maximum fertilization rate of 100 $kg.ha^{-1}$ N, 242 $kg.ha^{-1}$ P, and 179 $kg.ha^{-1}$ K.

4.2.3.1 Barley

Midseason dry matter production of barley was increased at Middleton's compared to the basal treatment by 126 $kg.ha^{-1}$ with the addition of banded K (treatment 6), but differences were not significant (Table 20). Application of broadcast P (treatment 7) increased midseason production to 638 $kg.ha^{-1}$, which was significantly greater than the basal treatment, but not significantly different than treatment 6. Broadcast K plus broadcast P (treatment 8) resulted in similar yields as treatment 7. At Glover's in 1982, yields were unaffected by banded K in relation to the basal treatment, and significantly increased to 896 $kg.ha^{-1}$ with broadcast P. The application of broadcast K plus P did not increase yield compared to broadcast P alone. In 1983, the application of banded K did not significantly increase yields compared to the basal treatment. Broadcast P increased yield to 689 $kg.ha^{-1}$, but this was not significantly different than the basal treatment which produced 552 $kg.ha^{-1}$ dry matter. Broadcast P plus K increased yields further to 831 $kg.ha^{-1}$, significantly better than the basal treatment, or basal plus banded K, but not significantly different than treatment 7.

High rates of nitrogen (200 $kg.ha^{-1}$) were applied in all treatments and the amount needed for higher yields could not be determined. An increase in rate of P fertilization from 22 $kg.ha^{-1}$ in a dual N-P band to 22 $kg.ha^{-1}$ in a band plus 220 $kg.ha^{-1}$ broadcast did give significant yield responses at Glover's. Data indicates that for high midseason yield, high rates of P are required in addition to high nitrogen. Response to K was variable. There was some evidence of response to

Table 20. Midseason Dry Matter Production of Barley in Study 1C ($kg.ha^{-1}$)

Treatment	Location and Year		
	Middleton 1982	Glover 1982	Glover 1983
9. basal*	445 b	446 b	582 b
6. basal + 29 K in band	571 ab	390 b	555 b
7. basal + 29 K in band + 220 P broadcast	638 a	896 a	689 ab
8. basal + 29 K in band + 220 P broadcast + 150 K broadcast	679 a	858 a	831 a

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 $kg.ha^{-1}$ N + 22 $kg.ha^{-1}$ P fall applied dual bands (40 cm spacing) plus 100 $kg.ha^{-1}$ spring broadcast N response to small amounts of K in band at Middleton's, where initial soil exchangeable K levels were low. However, it should be noted that the entire Middleton site received 70 kg.ha^{-1} K broadcast at the beginning of the study. Application of high rate broadcast K had little effect at any location.

At maturity, no significant differences in yield were noted due to treatment at Middleton's (Table 21). Yield with banded K was little different than yields produced with banded K plus broadcast P. Broadcast P plus K produced yields which were similar to yield of the basal treatment. This represented a change from midseason which showed a significant yield response to broadcast P and to broadcast P plus K. There is no obvious reason for this. At Glover's in 1982, banded K had virtually no effect on yield compared to the basal treatment. Yields were significantly increased to 4854 kg.ha^{-1} with broadcast P, and increased further to 5166 kg.ha^{-1} with broadcast P plus K. This was similar to the effect noted at midseason, and indicated that high rate P fertilization is necessary for high yield. At Glover's in 1983 yields were reduced by all treatments compared to the basal treatment. Band K reduced yield to 3108 kg.ha^{-1} from 3479 kg.ha^{-1} with basal treatment, although this difference was not significant. Broadcast P significantly reduced yield compared to the basal treatment, but this yield reduction was partially overcome with the application of broadcast K. The lack of a positive yield response in 1983 to high rate P fertilization may be due to a residual effect. The combined application rate of P over the 2 year study period on the treatment area totalled 484 kg.ha^{-1} P. If sufficient amounts of P remained

Table 21. Yield of Barley at Maturity in Study 1C (kg.ha^{-1})

	Location and Year		
Treatment	Middleton 1982 grain	Glover 1982 grain	Glover 1983 grain
9. basal*	3090	4107 b	3479 a
6. basal + 29 K in band	3756	4213 b	3108 ab
7. basal + 29 K in band + 220 P broadcast	3728	4854 a	2833 b
8. basal 29 K in band + 220 P broadcast + 150 K broadcast	3240	5166 a	3172 ab
	NS		

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P fall applied dual bands (40 cm spacing) plus 100 kg.ha^{-1} spring broadcast N

available from the 242 kg.ha^{-1} applied in 1982, it is unlikely that an additional 242 kg.ha^{-1} in 1983 would evoke a large response.

Nitrogen was applied to all plots at the same rate and by the same method. Differences in N uptake between treatments at midseason were thus attributed to the effect of P and K fertilization. Nitrogen uptake was increased compared to the basal treatment at all sites in response to application of P and K in accordance with yield response at midseason harvest (Table 22). While N uptake increased with high rate P and K broadcast applications, percent N in the plant was constant.

Phosphorus uptake at midseason at all locations was not significantly affected by banded K application (treatment 6) compared to the basal treatment (Table 23). Percent P was significantly increased at Glover's in 1983 with banded K compared to the basal treatment. This is in contrast with studies in 1984 by Harapiak and Penney which indicated that the addition of potash to an N-P band could interfere with P uptake by cereal crops from the band. Phosphorus uptake and % P were significantly increased with broadcast P application (treatment 7) compared to the basal treatment at all sites. Application of broadcast K plus P did not significantly affect P uptake compared to treatment 7, but did result in significantly reduced % P at Middleton's and Glover's in 1983.

Potassium uptake at Middleton's ranged from 11.9 in the control to 17.3 kg.ha^{-1} where K was broadcast, but differences were not significant (Table 24). At Glover's in 1982, K uptake significantly increased with the application of 220 kg.ha^{-1} P broadcast compared to the basal treatment, but % K was slightly lower than the basal

Table 22. Midseason Nitrogen Uptake (kg.ha^{-1}) and Concentration (%) in Barley in Study 1C

Treatment	Location and Year					
	Middleton 1982		Glover 1982		Glover 1983	
	uptake	%	uptake	%	uptake	%
9. basal +	24.3 b	5.46	23.1 b	5.18	30.7 b	5.27
6. basal + 29 K in band	31.0 ab	5.43	19.8 b	5.08	29.7 b	5.35
7. basal + 29 K in band + 220 P broadcast +	35.3 a	5.53	45.8 a	5.11	37.4 ab	5.43
8. basal + 29 K in band + 220 P broadcast + 150 K broadcast	38.3 a	5.64	44.2 a	5.15	44.4 a	5.34

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P fall applied dual bands (40 cm spacing) plus 100 kg.ha^{-1} spring broadcast N

Table 23. Midseason Phosphorus Uptake (kg.ha^{-1}) and Concentration (%) in Barley in Study 1C

Treatment	Location and Year					
	Middleton 1982		Glover 1982		Glover 1983	
	uptake	%	uptake	%	uptake	%
9. basal*	1.9 b	0.43 c	1.7 b	0.38 b	2.4 b	0.41 d
6. basal + 29 K band	2.5 b	0.44 c	1.4 b	0.36 b	2.5 b	0.45 c
7. basal + 29 K band + 220 P broadcast +	3.8 a	0.60 a	4.5 a	0.50 a	4.3 a	0.62 a
8. basal + 29 K in band + 220 P broadcast + 150 K broadcast	3.9 a	0.57 b	4.6 a	0.54 a	4.8 a	0.58 b

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P fall applied dual bands (40 cm spacing) plus 100 kg.ha^{-1} spring broadcast N

Table 24. Midseason Potassium Uptake ($kg.ha^{-1}$) and Concentration (%) in Barley in Study 1C

	Location and Year					
Treatment	Middleton 1982		Glover 1982		Glover 1983	
	uptake	%	uptake	%	uptake	%
9. basal	11.9	2.67	18.8 b	4.22	14.6 b	2.51
6. basal + 29 K band	15.4	2.70	17.3 b	4.44	13.1 b	2.36
7. basal + 29 K band + 220 P broadcast	14.9	2.34	36.4 a	4.06	17.8 ab	2.58
8. basal + 29 K band + 220 P broadcast + 150 K broadcast	17.3	2.55	38.7 a	4.51	21.8 a	2.62
	NS					

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 $kg.ha^{-1}$ N + 22 $kg.ha^{-1}$ P fall applied dual bands (40 cm spacing) plus 100 $kg.ha^{-1}$ spring broadcast N treatment and treatment 6. Broadcast K in addition to broadcast P plus basal plus banded K had no effect on K uptake. In 1983, K uptake was not significantly affected with either banded K, or banded K plus broadcast P (treatment 7). Broadcast P plus K resulted in significantly increased uptake compared to the basal treatment, or the basal treatment plus banded K, but % K was similar between all treatments.

Statistical analysis was not possible on nutrient uptake data at final harvest in 1982 due to bulking of samples by treatment prior to analysis. At maturity, N uptake data was variable (Table 25). At Middleton's, treatment 9, fertilized at the lowest rate, and treatment 6 (basal plus banded K) resulted in N uptake and N concentration substantially higher than treatments 7 and 8. At Glover's in 1982, N uptake increased as rate of fertilization increased, and while rate of N fertilization was constant, percent N increased with P or K fertilization compared to the basal treatment. In 1983, N uptake decreased significantly with broadcast P compared to the basal treatment, but was not significantly different from treatments 6 or 8. Percent N was not significantly affected by any treatment.

Phosphorus uptake at maturity was not affected by the application of banded K in 1982 at either site (Table 26). In 1983 at Glover's, banded K resulted in lower % P than the basal treatment, contrary to the results from midseason, and in support of studies by Harapiak and Penney (1984) that K placed in a band with N and P could interfere with P uptake. Phosphorus uptake and % P were significantly increased with the application of broadcast P, or broadcast P plus K compared to

Table 25. Nitrogen Uptake (kg.ha^{-1}) and Concentration (%) in Barley at Maturity in Study 1C

	Location and Year					
Treatment	Middleton 1982		Glover 1982		Glover 1983	
	uptake	%	uptake	%	uptake	%
9. basal	88.7	2.42	79.3	1.93	90.5 a	2.61
6. basal + 29 K band	89.7	2.39	96.0	2.28	81.4 ab	2.62
7. basal + 29 K band + 220 P broadcast	67.1	1.80	109.2	2.25	73.3 b	2.63
8. basal + 29 K band + 220 P broadcast + 150 K broadcast	61.9	1.91	113.7	2.20	81.6 ab	2.58
						NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P fall applied dual bands (40 cm spacing) plus 100 kg.ha^{-1} spring broadcast N

Table 26. Phosphorus and Potassium Uptake (kg.ha^{-1}) and Concentration (%) in Barley at Maturity in Study 1C

	Location and Year							
Treatment	Middleton 1982		Glover 1982		Glover 1983			
	Phosphorus		Phosphorus		Phosphorus		Potassium	
	uptake	%	uptake	%	uptake	%	uptake	%
9. basal	11.7	0.32	15.6	0.38	14.5 a	0.42 b	19.5 a	0.56
6. basal + 29 K in band	10.1	0.27	15.6	0.37	11.8 b	0.38 b	15.2 b	0.49
7. basal + 29 K in band + 220 P broadcast	13.4	0.36	23.9	0.49	14.1 a	0.50 a	14.7 b	0.54
8. basal + 29 K in band + 220 P broadcast + 150 K broadcast	9.7	0.30	24.2	0.47	15.6 a	0.49 a	17.3 a	0.55
								NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P fall applied dual bands (40 cm spacing) plus 100 kg.ha^{-1} spring broadcast N

treatment 6 or the basal treatment at all locations. Broadcast P plus broadcast K resulted in P uptake similar to broadcast P alone (treatment 7). Phosphorus concentration was significantly reduced in 1982 at Middleton's and in 1983 at Glover's with broadcast K plus broadcast P (treatment 8) compared to broadcast P alone (treatment 7).

Laboratory analysis of potassium content was conducted only in 1983. Potassium uptake was significantly decreased with banded K and broadcast P (treatments 6 and 7) compared to the basal treatment (Table 26). Broadcast K plus P (treatment 8) resulted in greater K uptake than treatments 6 or 7 but not significantly different than the basal treatment. Highest K uptake correlated to treatment 9, which was the only treatment that received no potassium. Percent K was not significantly affected by any treatment.

In summary, while barley on the Middleton site did not respond significantly to any treatment in addition to the basal treatment, applying N, P and K in a common band, plus 100 $kg.ha^{-1}$ N broadcast (treatment 6), was the most effective rate of fertilization. At Glover's in 1982, increasing fertilizer rates to a maximum of 200 $kg.ha^{-1}$ N, 242 $kg.ha^{-1}$ P and 179 $kg.ha^{-1}$ K (treatment 8) resulted in maximizing yield at 5166 $kg.ha^{-1}$. In 1983, yield was maximized by applying 100 $kg.ha^{-1}$ N broadcast, with 100 $kg.ha^{-1}$ N and 22 $kg.ha^{-1}$ P dual banded (treatment 9 or basal). The variation in response of barley to high rate fertilization could be attributed to limiting factors not evaluated in this study. This could include deficiencies of nutrients such as sulphur or micronutrients, as well as the possibility of a nutrient imbalance created by high rate N, P and K fertilization. Also, the plot in 1983 was located on the exact same land area as the plot in 1982 and therefore a high levels of nutrients would already be available and thus limit the expected response in 1983.

4.2.3.2 Rapeseed

Rapeseed was harvested only at maturity for yield and tissue analysis at Middleton's and Glover's in 1982 (Table 27). At Middleton's, although there were no significant differences in yield among fertility treatments, yield was increased compared to the basal treatment with the addition of banded K (treatment 6), and this was similar to yields produced by treatment 8. At Glover's, all treatments yielded higher than the basal treatment, but differences were not significant. Studies by Sheppard and Bates (1980) also showed that rapeseed yields were not increased by the application of 200 $kg.ha^{-1}$ N, 100 $kg.ha^{-1}$ P and 180 $kg.ha^{-1}$ K.

Statistical analysis was not possible on N and P uptake data due to bulking of samples by treatment prior to analysis (Table 28). Nitrogen uptake ranged from 37.8 to 47.3 $kg.ha^{-1}$ at Middleton's and 77.4 to 85.8 $kg.ha^{-1}$ at Glover's. Variation in uptake reflected variation in yield. Nitrogen concentration in the grain was similar between all treatments.

Phosphorus uptake by the grain at Middleton's ranged from a low of 8.0 $kg.ha^{-1}$ with treatment 7 to a high or 9.7 $kg.ha^{-1}$ with treatment 6. Percent P was constant and not affected by fertilization. However, P uptake at the Glover location was increased to 17.8 $kg.ha^{-1}$ with banded

Table 27. Yield of Rapeseed at Maturity in Study 1C ($kg.ha^{-1}$)

Treatment	Location and Year Middleton 1982 grain	 Glover 1982 grain
3. basal	1163	2049
6. basal + 29 K in band	1232	2195
7. basal + 29 K in band 220 P broadcast	1065	2208
8. basal + 29 K in band 220 P broadcast 150 K broadcast	1228	2214
	NS	NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 $kg.ha^{-1}$ N + 22 $kg.ha^{-1}$ P fall applied dual band (40 cm spacing)

Table 28. Nitrogen and Phosphorus Uptake (kg.ha^{-1}) and Concentration (%) in Rapeseed at Maturity in Study 1C

	Location and Year							
Treatment	Middleton 1982				Glover 1982			
	Nitrogen		Phosphorus		Nitrogen		Phosphorus	
	uptake	%	uptake	%	uptake	%	uptake	%
3. basal	44.9	3.91	8.5	0.73	77.7	3.79	12.9	0.63
6. basal + 29 K in band	47.4	3.94	9.7	0.79	85.8	3.91	17.8	0.81
7. basal + 29 K in band + 220 P broadcast	37.8	3.62	8.0	0.75	84.5	3.83	20.6	0.94
8. basal + 29 K in band + 220 P broadcast + 150 K broadcast	47.3	3.90	8.6	0.70	81.7	3.69	20.6	0.93

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P fall applied dual band (40 cm spacing)

K from 12.9 kg.ha^{-1} in basal treatment, and further increased to 20.6 kg.ha^{-1} with high rate broadcast P (treatment 7) and broadcast P plus K (treatment 8). Phosphorus concentration was also increased to 0.94 % with broadcast P from 0.63 % in basal treatment. Application of high rate broadcast K in addition to broadcast P did not affect P uptake or % P compared to broadcast P alone. The large increase in % P associated with high rate broadcast P, although yield did not increase, indicated that P was available in sufficient quantities to meet the crop's requirement and some other factor limited yield.

4.2.3.3 Flax

Midseason samples of flax were harvested only in 1983. Dry matter production decreased with banded K as compared to the basal treatment, and increased with the application of broadcast P (treatment 7) and broadcast P plus K (treatment 8), although differences were not significant (Table 29). Nitrogen uptake ranged from 41.2 to 52.0 kg.ha^{-1} and reflected variation in yield. Nitrogen concentration was not significantly affected by treatment. Phosphorus uptake was significantly increased over treatments 3 and 6 when 220 kg.ha^{-1} P was broadcast, and % P was increased to 0.51 % from 0.29 % in the basal treatment. Application of broadcast P plus K resulted in P uptake significantly greater than the basal treatment, but not significantly different from broadcast P alone (treatment 7). However % P was significantly reduced with broadcast P plus K compared to broadcast P alone. Potassium uptake was not significantly affected by any treatment, but ranged from 19.0 kg.ha^{-1} in basal treatment to 25.2

Table 29. Midseason Dry Matter Production of Flax and Nitrogen, Phosphorus and Potassium Uptake ($kg.ha^{-1}$) and Concentration (%) in Flax in 1983 in Study 1C

Treatment		Location and Year					
				Glover 1983			
	Yield	Nitrogen		Phosphorus		Potassium	
		uptake	%	uptake	%	uptake	%
3. basal	1245	42.8	3.44	3.6 b	0.29 c	19.0	1.53
6. basal + 29 K in band	1150	41.2	3.58	3.2 b	0.28 c	22.1	1.92
7. basal + 29 K in band + 220 P broadcast +	1380	49.3	3.57	7.1 a	0.51 a	25.2	1.83
8. basal + 29 K in band + 220 P broadcast + 150 K broadcast	1492	52.0	3.49	5.9 a	0.40 b	21.4	1.43
	NS	NS	NS			NS	

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 $kg.ha^{-1}$ N + 22 $kg.ha^{-1}$ P fall applied dual band (40 cm spacing) kg.ha^{-1} with treatment 7. Percent K was highest with banded K plus P and lowest with high rate broadcast K. It appeared that 29 kg.ha^{-1} K placed in the N-P dual band was adequate to meet the crop's early season potassium requirement and produce good midseason yields.

Flax grain yields in 1982 were variable but were not significantly affected by treatment (Table 30). High rate broadcast P yielded 1393 kg.ha^{-1}, lower than the basal treatment which yielded 1515 kg.ha^{-1}. The yield reduction associated with broadcast P was overcome with high rate broadcast K achieving a maximum yield of 1626 kg.ha^{-1}. Straw yields were similar among treatments and not significantly affected by treatment. In 1983, the same seed yield depression apparent in 1982 with broadcast P was noted to an even greater extent. Yields were reduced almost 50 % with high level P fertilization, and only partially recovered with high K fertilization. This could be related to a phosphate induced zinc deficiency as noted by other researchers (Burleson et al, 1961).

Statistical analysis was not possible on N, P and K uptake data in 1982 due to bulking of samples by treatment prior to analysis. Flax N uptake in grain and straw in 1982 was slightly variable but consistent with yield variation (Table 31). In 1983, N uptake by grain was significantly reduced with high rate broadcast P compared to other treatments, consistent with differences in yield, but % N was higher with treatment 7 than treatments 6 or 8 and similar to basal. However, straw N uptake data was significantly increased with broadcast P compared to the basal treatment or basal plus banded K. Similarly, % N in straw increased to 0.87 % with broadcast P from 0.58 % with basal

Table 30. Yield of Flax at Maturity in Study 1C (kg.ha^{-1})

Treatment	Glover 1982 grain	Glover 1982 straw	Glover 1983 grain	Glover 1983 straw
3. basal	1515	2745	985 a	2398
6. basal + 29 K in band	1546	2801	1109 a	2527
7. basal + 29 K in band + 220 P broadcast	1393	3065	548 c	2230
8. basal + 29 K in band + 220 P broadcast + 150 K broadacast	1626	3150	810 b	2318
	NS	NS		NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P fall applied dual band (40 cm spacing)

Table 31. Nitrogen Uptake (kg.ha^{-1}) and Concentration (%) in Flax at Maturity in Study 1C

	Location and Year							
Treatment	Glover 1982				Glover 1983			
	grain		straw		grain		straw	
	uptake	%	uptake	%	uptake	%	uptake	%
3. basal	53.0	3.50	19.2	0.70	38.6 ab	3.92	13.9 bc	0.58
6. basal + 29 K in band	52.7	3.41	19.0	0.68	40.2 a	3.62	12.2 c	0.48
7. basal + 29 K in band + 220 P broadcast	49.2	3.53	24.8	0.81	22.0 c	4.01	19.5 a	0.87
8. basal + 29 K in band + 220 P broadcast + 150 K broadcast	55.3	3.40	20.8	0.66	31.2 b	3.85	16.3 ab	0.70

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P fall applied dual band (40 cm spacing)

treatment.

Phosphorus uptake and % P in the grain in 1982 increased with rate of fertilization except for a slight decrease with treatment 6 (Table 32). A pronounced increase in straw P uptake was noted with high rate broadcast P, and % P in straw was doubled with broadcast P compared to the basal treatment. In 1983, P uptake in the grain was significantly reduced by 220 kg.ha^{-1} broadcast P compared to the basal treatment, which corresponded to differences in yield, but percent P increased significantly with broadcast P compared to the basal treatment. Phosphorus uptake in the straw was significantly increased with broadcast P application compared to other treatments, and % P increased significantly from 0.04 % in the basal treatment to 0.13 % with broadcast P. It is interesting to note that broadcast P applications of 220 kg.ha^{-1} resulted in reduced grain yields compared to the basal treatment, but did not affect straw production. Also, while % N and % P in the grain was generally reduced by P fertilization, large amounts of N and P accumulated within the straw. As rate of fertilization was increased further with 150 kg.ha^{-1} K, grain yields improved, % N and P in the grain remained constant, and % N and P in the straw decreased. While this phenomenon could not be explained, it may indicate an interaction occurring between phosphorus and potassium at high levels of fertilization.

Tissue analysis for potassium content was conducted only in 1983. Potassium uptake by the grain increased to 7.0 kg.ha^{-1} when rate of K fertilization was increased to 150 kg.ha^{-1} K from 5.3 kg.ha^{-1} in the basal treatment, but differences were not significant (Table 33).

Table 32. Phosphorus Uptake (kg.ha^{-1}) and Concentration (%) in Flax in Study 1C

	Location and Year							
Treatment	Glover 1982				Glover 1983			
	Grain		Straw		Grain		Straw	
	uptake	%	uptake	%	uptake	%	uptake	%
3. basal	8.2	0.54	2.2	0.08	6.1 a	0.62 b	0.84 c	0.04 c
6. basal + 29 K in band	7.4	0.48	1.9	0.07	5.9 a	0.53 c	0.86 c	0.03 c
7. basal + 29 K in band + 220 P broadcast	9.5	0.68	4.9	0.16	3.7 b	0.68 a	2.8 a	0.13 a
8. basal + 29 K in band + 220 P broadcast + 150 K broadcast	10.9	0.67	3.5	0.11	5.4 a	0.67 a	1.9 b	0.08 b

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P fall applied dual band (40 cm spacing)

Table 33. Potassium Uptake (kg.ha^{-1}) and Concentration (%) in Flax in Study 1C

Treatment	Location and Year			
	Glover 1983			
	Grain		Straw	
	uptake	%	uptake	%
3. basal	5.3 ab	0.54 b	8.0 b	0.33 b
6. basal + 29 K in band	5.4 ab	0.48 b	10.3 ab	0.41 ab
7. basal + 29 K in band + 220 P broadcast	4.0 b	0.76 a	10.0 ab	0.45 a
8. basal + 29 K in band + 220 P broadcast + 150 K broadcast	7.0 a	0.86 a	11.0 a	0.48 a

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*basal = 100 kg.ha^{-1} N + 22 kg.ha^{-1} P fall applied dual band (40 cm spacing)

Potassium uptake with treatment 7 was significantly less than that of treatment 8. Potassium concentration (%) in both the grain and straw was not increased compared to the basal treatment with 29 kg.ha^{-1} K banded with N-P dual band, but then increased with broadcast P (treatment 7) and broadcast P plus K (treatment 8).

4.2.3.4 Summary

In summary, yield response of barley to high levels of applied N, P and K was variable. Rates of 200 kg.ha^{-1} N, 220 kg.ha^{-1} P and 179 kg.ha^{-1} K were beneficial in increasing yield and % P at one site, while lower rates produced higher yields at other sites. Inconsistent response to fertilization was likely due to a residual effect in 1983 or a deficiency of nutrients not evaluated in this study. Rapeseed yields were not affected by rates of fertilization above the basal treatment. Dual bands of N and P at rates of 100 kg.ha^{-1} N and 22 kg.ha^{-1} P were as effective as 100 kg.ha^{-1} N banded, and broadcast applications of 220 kg.ha^{-1} P and 179 kg.ha^{-1} K. Response of flax was variable. No significant response was obtained in 1982, although yield was maximized at 1626 kg.ha^{-1} with high rates of all fertilizers. In 1983, the most effective rate of fertilization was 100 kg.ha^{-1} N, 22 kg.ha^{-1} P and 29 kg.ha^{-1} K. Higher rates reduced yield, possibly due to P and K interactions at high fertilization rates.

5. Field Study 2

5.1 The Effect of Phosphorus Placement on Yield and Phosphorus Recovery by Flax and Canola

5.1.1 Introduction

Results from Study 1 were generally variable due largely to inconsistent response to P. Rapeseed and flax yields did not respond to phosphorus fertilization at the Middleton site, but did respond favorably to narrow dual band placement of P at the Glover location. Thus, a second experiment was conducted to further evaluate the effect of P placement as well as rate of P fertilization on canola and flax on a phosphate deficient soil. Methods of P placement included dual N-P bands, separate bands of N and P, seed row P, split P and broadcast P, and each method was evaluated using two rates of P fertilization. In addition, seed row P and banded P treatments were evaluated with two placements of nitrogen, i.e. banded or broadcast.

5.1.2 Material and Methods

A plot site was established in the spring of 1983 on a Gleyed Cumulic Regosol silty clay soil of the Gervais Series (Table 34). Nitrogen, potassium and sulphur levels were high to very high and considered adequate to sustain crop development. Available phosphorus level was very low and therefore response to applied P was expected. The soil was neutral to slightly basic in pH, non saline and had a high

Table 34. Characteristics of Plot Soil Used in Study 2

Classification	Gleyed Cumulic Regosol
Series	Gervais SiC
NO_3-N (kg.ha^{-1} to 60 cm depth)	135
$NaHCO_3$ extractable P (kg.ha^{-1} to 15 cm depth)	5.0
NH_4OAc extractable K (kg.ha^{-1} to 15 cm depth)	311
SO_4-S (kg.ha^{-1} S to 60 cm depth)	268
pH (in water)	7.7
$CaCO_3$ equivalent (%)	25.3
Conductivity (dS.m^{-1} to 15 cm depth)	1.3

calcium carbonate content.

Two separate blocks were established, one for flax and the other for canola. The experimental design on each block was a completely randomized block design with 19 treatments and 4 replicates (Table 35). Treatment plots consisted of 8 seed rows (17.8 cm spacing) 7.6 m long. Treatments consisted of a series of placements of N and P, utilizing 2 rates of P. Two rates of P were used, a recommended rate (10 $kg.ha^{-1}$) and a high rate (20 $kg.ha^{-1}$) because of the possibility that recommended rates of P were inadequate. All fertilizer was spring applied. Nitrogen, applied as urea, was banded or broadcast. Phosphorus was placed either in a band, with the seed or broadcast as monoammonium phosphate (MAP). Dual bands were spaced 40 cm apart and placed 10 to 12 cm deep using a deep bander with 5 cm wide chisel points. Separate bands were applied by making 2 passes with the applicator, offsetting the bander by 20 cm in the second pass. Nitrogen was applied in the first pass, and phosphorus in the second pass resulting in alternating bands of N and P spaced 20 cm apart. Broadcast fertilizer applications were incorporated with one shallow disc operation. A firm seedbed was prepared with 2 operations using a spike harrow after banding.

Canola (Brassica napus var Regent) and flax (Linum usitatissimum var Dufferin) were seeded at 7 and 40 $kg.ha^{-1}$ respectively, parallel to fertilizer bands, with an 8 run double disc seeder (17.8 cm row spacing). Recommended herbicides were used for weed control.

Canola and flax were sampled 40 and 47 days after seeding, respectively, for total above ground yield and nutrient analysis. The

Table 35. Treatments Applied in Field Study 2 for Flax and Canola

Treatment	N applied (kg.ha^{-1})	P applied (kg.ha^{-1})
1. 0 P, N band	50	0
2. P band, 0 N	0	10
3. P band, 0 N	0	20
4. dual band	50	10
5. dual band	50	20
6. separate bands	50	10
7. separate bands	50	20
8. P band, N broadcast	50	10
9. P band, N broadcast	50	20
10. seed row P, 0 N	0	10
11. seed row P, 0 N	0	20
12. seed row P, N broadcast	50	10
13. seed row P, N broadcast	50	20
14. seed row P, N band	50	10
15. seed row P, N band	50	20
16. split P*, N band	50	20
17. split P, N band	100	20
18. P broadcast, N broadcast	50	20
19. P broadcast, N broadcast	50	40

*split P refers to equal division of P between seed row and band

N applied as urea (46-0-0); P applied as monoammonium phosphate (11-55-0) harvest area was 4 rows x .61 m (0.43 m^2). At maturity, 4 rows x 6.1 m (4.3 m^2) of the flax plots were harvested for yield and nutrient analysis. The canola plot was not harvested as it was inadvertently destroyed by the cooperator prior to final harvest.

Due to the large number of treatments applied in this study, statistical analysis of all 19 treatments concurrently was difficult to interpret. Therefore, treatments were grouped into 3 categories of method of P placement, rate of P applied, and method of N placement, and statistical analysis was conducted within each category. To determine the effect of method of P placement, treatments were grouped according to actual P placement, regardless of the rate of P applied, or placement of N. Thus for evaluation of method of P placement treatments were grouped as follows:

A. 0 P (control) - treatment 1;
B. band P (0 N or broadcast N) - treatments 2, 3, 8 and 9;
C. dual bands - treatments 4 and 5;
D. separate bands - treatments 6 and 7;
E. seed row P - treatments 10, 11, 12, 13, 14 and 15;
F. split P - treatments 16 and 17;
G. broadcast P - treatments 18 and 19.

For example, group E (seed row P) focused on all treatments where P was placed with the seed, regardless of rate of P applied, and also included treatments where N was broadcast, banded or not applied at all. Similarly, the effect of rate of P applied was evaluated by grouping treatments by rate of P fertilization, regardless of method of P or N application. These groupings were as follows:

H. 0 P (control) - treatment 1;

I. 10 kg.ha^{-1} - treatments 2, 4, 6, 8, 10, 12 and 14;

J. 20 kg.ha^{-1} - treatments 3, 5, 7, 9, 11, 13, 15, 16, 17 and 18;

K. 40 kg.ha^{-1} - treatment 19.

The effect of N placement was evaluated using the following groupings:

L. 0 N (control) - treatments 2, 7, 10 and 11;

M. broadcast N - treatments 8, 9, 12, 13, 18 and 19;

N. band N - treatments 1, 4, 5, 6, 7, 14, 15, 16 and 17.

5.2 <u>Results and Discussion</u>

5.2.1 <u>Introduction</u>

Soil moisture conditions at seeding were good, and adequate to sustain uniform germination and emergence. Subsurface soil was close to saturated, resulting in some problems with banded fertilization application, such as plugging of nozzles. Precipitation occurred at regular intervals throughout the growing season, and at no time did the crops experience moisture stress.

5.2.2 <u>Canola</u>

Midseason dry matter production of canola was significantly increased by split P placement, P applied in the seed row, and broadcast P compared to the control (Table 36). Banded phosphorus increased yields compared to the control, but not significantly. The apparent disadvantage of band placement, compared to other placements could be related to soil disturbance caused by spring banding, which

Table 36. Midseason Dry Matter Production ($kg.ha^{-1}$), Phosphorus Uptake ($kg.ha^{-1}$) and Concentration (%) of Canola as Affected by Phosphorus Placement in Study 2

Phosphorus Placement	Yield	Phosphorus uptake	%
A. control (0 P)	901 b	1.9 c	0.21 d
B. band P, broadcast N or 0 N	1280 b	5.6 ab	0.44 a
C. dual bands	1097 b	5.3 b	0.48 a
D. separate bands	1282 b	5.6 ab	0.44 a
E. seed row P	2100 a	6.0 ab	0.29 c
F. split P	2226 a	7.6 a	0.34 bc
G. broadcast P	2015 a	7.5 a	0.37 b

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Table 37. Midseason Dry Matter Production ($kg.ha^{-1}$), Phosphorus Uptake ($kg.ha^{-1}$) and Concentration (%) of Canola as Affected by Rate of Phosphorus Application in Study 2

Rate of P applied	Yield	Phosphorus uptake	%
H. 0 (control)	901 c	1.9 c	0.21 b
I. 10	1523 b	5.0 b	0.33 a
J. 20	1788 b	6.6 b	0.37 a
K. 40	2419 a	9.2 a	0.38 a

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

resulted in a poor seedbed and moisture loss. Canola has also been observed to respond very favorably to P placed in the seed row under low soil test P levels (Harapiak, 1980). This could in part explain the excellent advantage of seed row placement over bands observed in this study.

Phosphorus uptake was greater than the control by at least 2.5 times as a result of all methods of P placement. Phosphorus uptake was greatest when P was placed in the seed row, split between the seed row and band, or broadcast, which relates to large yield increases associated with those treatments. Phosphorus concentration ranged from 0.29 % to 0.37 % with these treatments, significantly greater than % P in the control. When P was banded, P uptake was increased compared to the control, and % P within the plant ranged from 0.44 % to 0.48 %, significantly greater than P concentration with other placements. This may be due to a delay in plant roots reaching banded P, thus increased plant P concentration was not manifested by yield at the 40 day post-seeding harvest date.

Dry matter production of canola at midseason increased significantly with the application of P at 10, 20 and 40 $kg.ha^{-1}$ (Table 37). Rates of 10 and 20 $kg.ha^{-1}$ P increased dry matter production about 1.5 times compared to the control. The application of 40 $kg.ha^{-1}$ P resulted in yields 2.5 times greater than the control, and significantly greater than the 10 or 20 $kg.ha^{-1}$ rates. This comparison is confounded however because 40 $kg.ha^{-1}$ P was a broadcast application, whereas the 20 $kg.ha^{-1}$ P was either broadcast, placed in the seed row, split between the seed row and band, or banded.

Phosphorus uptake and P concentration also increased significantly with increased rate of P application. Percent P increased to 0.33 % when P was applied at 10 kg.ha^{-1}, from 0.21 % in the control, but did not increase further at higher rates of applied P.

The effect of broadcast and banded N on yield and P uptake are shown in Table 38. Broadcast N application increased yields compared to the control, but differences were not significant. Banded N resulted in decreased yields compared to the control although not significantly. This may have been due to poor emergence and crop establishment resulting from soil disturbance caused by band application. Phosphorus uptake and concentration were not significantly affected by method of N placement.

5.2.3 Flax

Flax yields at midseason were increased by all methods of application of P, however yields were not significantly different from the control (Table 39). Broadcast P, split P placement and seed row P applications produced more dry matter at midseason than any of the banded treatments. Phosphorus uptake for treatments receiving P was not significantly different from the control. However uptake with all banded P treatments was lower than uptake of the control. Phosphorus concentration was highest in the control plot, but not significantly different than treatments that received P. This in contrast to canola, which absorbed more P when phosphorus was banded. This supports the findings of Soper and Kalra (1969), that rapeseed is more efficient at extracting P from a concentrated source than flax.

Table 38. Midseason Dry Matter Production ($kg.ha^{-1}$), Phosphorus Uptake ($kg.ha^{-1}$) and Concentration (%) of Canola as Affected by Nitrogen Placement in Study 2

Nitrogen Placement	Yield	Phosphorus uptake	Phosphorus %
L. control (0 N)	1630 ab	5.4 a	0.33
M. broadcast N	1834 a	6.5 a	0.35
N. band N	1593 b	5.7 a	0.36
			NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test)

Table 39. Midseason Dry Matter Production ($kg.ha^{-1}$), Grain Yield at Maturity, Phosphorus Uptake ($kg.ha^{-1}$) and Concentration (%) of Flax as Affected by Phosphorus Placement in Study 2

Phosphorus Placement	Midseason Yield	Midseason Phosphorus uptake	Midseason Phosphorus %	Final Yield	Final Phosphorus uptake	Final Phosphorus %
A. control (0 P)	1178	2.3 ab	0.20	637	3.3	0.52
B. band P	1233	2.0 ab	0.16	702	3.5	0.50
C. dual band	1218	2.0 ab	0.16	708	3.4	0.48
D. separate bands	1198	1.9 b	0.16	782	3.6	0.46
E. seed row P	1430	2.5 a	0.17	728	3.2	0.44
F. split P	1435	2.4 ab	0.17	706	3.2	0.45
G. broadcast P	1498	2.5 a	0.17	760	3.7	0.49
	NS		NS	NS	NS	NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Final yields of flax were comparable to the 1983 average regional production of 956 kg.ha^{-1} (Manitoba Agriculture Yearbook, 1983). There was no significant effect of P placement on yield (Table 39). This was attributed to severe weed infestations that were not controlled by herbicides. All methods of phosphorus placement increased yield over the control although not significantly. Total P uptake ranged from 3.2 to 3.7 kg.ha^{-1} and differences were not significant.

Flax yields at midseason increased from 1178 kg.ha^{-1} in the control to 1432 kg.ha^{-1} with 40 kg.ha^{-1} P broadcast, but differences were not significant (Table 40). Phosphorus uptake was not significantly affected by rate of P fertilization, and P concentration was again highest (0.20 %) in the control plot. In general, P concentration at the 40 day harvest were low compared to work conducted by other researchers (Racz et al, 1965).

Flax grain yields were increased by all rates of P applied, however yields were not significantly different from the control. Phosphorus uptake ranged from 3.3 to 3.7 kg.ha^{-1}, and concentration was highest in the control plot at 0.52 %. Differences in P uptake and P concentration between treatments were not significant.

Broadcast nitrogen significantly increased flax yields at midseason, and both broadcast and banded N significantly increased yields at final harvest over the control (Table 41). The effect of method of N application on phosphorus uptake is also shown in Table 41. Phosphorus uptake was significantly increased with broadcast N at midseason compared to the control, but % P was similar between treatments. At final harvest, P concentration was highest in the

Table 40. Midseason Dry Matter Production (kg.ha^{-1}), Grain Yield at Maturity and Phosphorus Uptake (kg.ha^{-1}) and Concentration (%) of Flax as Affected by Rate of Phosphorus Application in Study 2

Rate of P applied	Midseason			Final		
	Yield	Phosphorus uptake	%	Yield	Phosphorus uptake	%
H. 0 (control)	1178	2.3	0.20	637	3.3	0.52
I. 10	1285	2.2	0.17	700	3.3	0.47
J. 20	1378	2.3	0.17	743	3.4	0.46
K. 40	1432	2.4	0.17	756	3.7	0.49
	NS	NS	NS	NS	NS	NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Table 41. Midseason and Final Grain Yield (kg.ha^{-1}) and Phosphorus Uptake (kg.ha^{-1}) and Concentration (%) of Flax as Affected by Nitrogen Placement in Study 2

Nitrogen Placement	Midseason			Final		
	Yield	Phosphorus uptake	%	Yield	Phosphorus uptake	%
L. (control) 0 N	1232 b	2.2 b	0.18	650 b	3.3	0.51
M. broadcast N	1481 a	2.5 a	0.17	764 a	3.5	0.46
N. band N	1286 b	2.2 b	0.17	727 a	3.3	0.45
			NS		NS	NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

control at 0.51 % , and decreased to 0.46 % when N was applied, but differences were not significant.

5.2.4 Summary

In summary, canola dry matter production at midseason harvest was increased by seed row and split P placements, but not by dual band placement, as in Study 1. These results support placement studies with canola by Toews (1982). Production increased with rate of P applied, to a maximum of 2419 $kg.ha^{-1}$ at an application rate of 40 $kg.ha^{-1}$ P. Phosphorus recovery by canola at midseason was significantly increased with the addition of phosphorus at all rates. Broadcast nitrogen application increased yield significantly compared to band N placement, but neither method resulted in significant differences from the control. Flax yields at midseason and final harvest were again not affected by phosphorus application by any method or rate. Broadcast N (where P was banded, placed in the seed row, or broadcast) was more effective in increasing flax yields than banded N or the 0 N treatment at midseason. No significant effect of N placement on flax yield was evident at final harvest.

6. Pot Study A

6.1 The Effect of Phosphorus Placement, Nitrogen Carrier and Freeze Treatment on Dry Matter Production and Phosphorus Recovery by Barley using ^{32}P

6.1.1 Introduction

Fall applied fertilizer is subjected to a lengthy cold period in the winter months, and during the freezing and spring thawing processes N and P fertilizer may undergo changes that could reduce its effectiveness. Urea added to a cold soil has been shown to result in nitrite accumulation due to incomplete nitrification (Christianson and Cho, 1979). Nitrite then undergoes chemical denitrification to form N gases. Rate of denitrification is temperature related and was found to decrease as temperature drops from 20°C to 0°C. As temperature decreases further to -3.5°C, rate of denitrification increased dramatically, and slowed again at temperatures below -3.5°C. The high rate of denitrification occurring between 0 and -3.5°C can result in large losses of fall applied N.

In Study 1B (Section 4.2.2), the effectiveness of fall and spring applied dual N-P bands was compared in a two year field experiment with barley. Results were variable. Spring placed bands were superior in 1982 to fall placed bands as measured by barley yield, but in 1983 fall bands were superior to spring bands. A pot experiment was undertaken to further evaluate the effect of fall and spring applied phosphorus on yield and P recovery by barley. This study involved several methods of placement of ^{32}P tagged monoammonium phosphate. The effect of fall versus spring banding was simulated with a frozen period after fertilizer application.

6.1.2 Material and Methods

A carbonated and a noncarbonated soil were selected for this study (Table 42). Soils were air dried, sieved to 2 mm and 5 kg soil was weighed into 5 liter plastic pots.

The experiment consisted of a frozen and a nonfrozen set of treatments. Treatments included in the nonfrozen set are shown in Table 43. Treatments included in the frozen set are also shown in Table 43 but treatments 8 and 10 are excluded. Each treatment was replicated 3 times and was conducted on 2 soils. The study focused on treatments involving dual and separate band placements of MAP with urea, ammonium nitrate, or ammonium sulphate, along with a banded P and broadcast N treatment and a control. Different N carriers were used because the source of N has been shown to have an effect of P availability (Leonce and Miller, 1966; Olson and Drier, 1956). A broadcast P and broadcast N treatment was also included for continuity because it had been included in the previous field study (this treatment was not ^{32}P labelled). The frozen set was subjected to a freezing period after fertilizer application, but before seeding to simulate the effect of freezing and thawing processes of winter conditions on fall applied fertilizer. The nonfrozen set was seeded immediately after fertilizer application.

For both the frozen and nonfrozen treatments, phosphorus was

Table 42. Characteristics of Soils Used in Pot Study A

	Plot Site	
Characteristic	Carbonated	Noncarbonated
Classification	Gleyed Rego Black (Carbonated)	not available
Series	Almasippi LS	Gladstone SL
NO_3-N ppm (ppm to 15 cm depth)	5.6	6.0
$NaHCO_3$ extractable P (ppm to 15 cm depth)	9.6	8.6
NH_4OAc extractable K (ppm to 15 cm depth)	75	120
SO_4-S (ppm to 15 cm depth)	1.9	2.3
pH (in water)	8.1	7.8
$CaCO_3$ equivalent (%)	15.8	1.9
Conductivity $dS.m^{-1}$ to 15 cm depth)	0.3	0.3
moisture at field capacity (%)	22	23

Table 43. Treatments Applied in Pot Study A

P carrier	N carrier	Placement
1. MAP	urea	dual band
2. MAP	urea	separate bands
3. MAP	ammonium nitrate	dual band
4. MAP	ammonium nitrate	separate bands
5. MAP	ammonium sulphate	dual band
6. MAP	ammonium sulphate	separate bands
7. 0 P	urea	band
8. *0 P	urea	broadcast
9. MAP	urea	P band, N broadcast
10. *MAP	urea	P seed row, N broadcast
11. MAP**	urea	P broadcast, N broadcast

*Nonfrozen set only

**Not labelled with ^{32}P

Basic fertilizer rate: 25 ppm P (56 $kg.ha^{-1}$), 50 ppm N (112 $kg.ha^{-1}$)

applied as monoammonium phosphate (11-55-0) labelled with ^{32}P in the form of orthophosphoric acid. Two millicuries of ^{32}P were obtained from New England Nuclear, Montreal, Canada, and diluted in 250 ml of 25 ppm P solution (56 $kg.ha^{-1}$). Aliquots were mixed with prepared N solutions to be used for band application. The broadcast P treatment was not labelled. Banded nitrogen was applied at 50 ppm N (112 $kg.ha^{-1}$) as urea (46-0-0), ammonium nitrate (34-0-0) or ammonium sulphate (21-0-0(24)). Broadcast N was applied as urea.

Fertilizer in separate bands was placed 5 cm below the seed and 5 cm on either side. Fertilizer in dual bands was placed 5 cm below the seed and 5 cm to one side. Broadcast fertilizer was applied at time of seeding and incorporated into the top 1 cm of soil. Pots were seeded with 10 kernels of barley (Hordeum vulgare var Conquest) placed at a depth of 1.5 cm parallel to the bands. Six days after emergence, plants were thinned to 5 plants per pot. Care was taken to ensure healthy well spaced plants remained. The fresh set was seeded within 24 hours of fertilization, and brought to field capacity by adding water to the pot surface. The frozen set was brought to field capacity after band application, covered tightly, left at room temperature for 12 days, and then frozen. After being frozen for 16 days, they were returned to room temperature and allowed to equilibrate for 12 days. Seeding was accomplished in the same manner as the nonfrozen set.

All pots received an additional 4 ppm (9 $kg.ha^{-1}$) of $CuSO_4$, 8 ppm (19 $kg.ha^{-1}$) $ZnSO_4$, 40 ppm K (90 $kg.ha^{-1}$) as K_2SO_4 and 50 ppm N as urea as a solution, 25 days after seeding, to ensure that these nutrients would not be limiting to growth. Thirty five days after seeding, another 100 ppm N was applied to meet additional N requirements.

Due to a shortage of growth bench space, the frozen and nonfrozen sets could not be run concurrently. Thus, the nonfrozen set was conducted from mid December to early February, while the frozen set was run from late January to mid March. This resulted in some problems in rate of plant growth because the environmental conditions, such as room temperature and relative humidity, could not be absolutely controlled. Air temperature in the growth bench area fluctuated with outdoor temperature. By mid March the daily outdoor temperature was considerably warmer than it had been in January, which resulted in the temperature of the growing period of the frozen set ranging from 27 to 30°C and higher, while the growth room temperature of the nonfrozen set ranged from 23 to 27°C.

Light conditions of the growth bench were set at 15 hours daylight and 9 hours darkness. Soil moisture was maintained at a range of 75 % to 100 % field capacity by adding water to the soil surface.

Plants were harvested at the late boot to heading stage (53 days). Plant tissue was dried at 60°C, ground, and analyzed for total P and Pdff as outlined in Chapter 3.

6.2 Results and Discussion

At the harvest date barley in the frozen set was at a more mature physiological stage than the nonfrozen set, and greater amounts of dry matter had been produced due to environmental conditions having changed during the course of the experiment. As a result, statistical analysis on the two sets was conducted separately, and the true effect of freezing and thawing was further evaluated in a later pot experiment. Within each set, analysis of variance was conducted by combining the data with respect to soil type and evaluating the treatment effect. Then the treatment data was combined and analysis of variance was conducted on the effect of soil carbonates. A third analysis of variance was conducted on treatment and soil carbonate data separately to determine if treatment-soil interactions occurred.

Dry matter yields of barley in the nonfrozen set ranged from 8.2 to 9.8 $g.pot^{-1}$, and were significantly increased compared to the control only with MAP plus urea broadcast (treatment 11), and seed row P plus urea broadcast (treatment 10) (Table 44). However, treatments 10 and 11 did not significantly differ from separate bands of MAP and ammonium nitrate (treatment 4), dual bands of MAP and ammonium sulphate (treatment 5) or separate bands of MAP and ammonium sulphate (treatment 6). Differences among N carrier or method of placement were not significant.

The high dry matter production resulting from broadcast applications of MAP and urea (treatment 11) was accompanied by significantly increased P uptake compared to other treatments. Phosphorus uptake was lowest in zero P treatments and was significantly increased by all treatments in the nonfrozen set except with separate bands of MAP plus urea (treatment 2) and dual bands of MAP plus ammonium nitrate (treatment 3).

Total Pdff values could be determined only on treatments which received ^{32}P, which therefore excluded control pots and treatments

Table 44. Effect of Treatment on Dry Matter Production, Phosphorus Uptake and Total Pdff of Barley in Nonfrozen Set in Pot Study A

Treatment	Yield	P uptake	Total Pdff
P N Placement	(g.pot $^{-1}$)	(mg.pot $^{-1}$)	(mg.pot $^{-1}$)
1. MAP, urea, dual	8.3 c	26.2 bc	6.0 c
2. MAP, urea, separate	8.2 c	25.2 cd	8.0 bc
3. MAP, A.N., dual	8.4 bc	25.2 cd	8.0 bc
4. MAP, A.N., separate	8.9 abc	27.8 bc	8.8 b
5. MAP, A.S., dual	8.9 abc	26.2 bc	7.1 bc
6. MAP, A.S., separate	9.0 abc	29.0 bc	8.1 bc
7. 0 P, urea, band	8.2 c	21.2 d	----
8. 0 P, urea, broadcast	8.2 c	21.4 d	----
9. MAP band; urea broadcast	9.1 abc	27.6 bc	8.6 b
10. MAP seed row; urea broadcast	9.4 ab	30.4 b	11.7 a
11. MAP, urea, broadcast	9.8 a	36.3 a	----

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

where both N and P were broadcast. In the nonfrozen set Pdff ranged from 6.0 to 11.7 mg.pot^{-1}, and increased significantly when P was applied with the seed compared to banded treatments. This indicated that seed row P is readily available to the roots, and is more accessible than phosphorus placed at 5 cm below and 5 cm to the side of the seed row. There was no evidence that seed row P, applied at 25 ppm (56 kg.ha^{-1}) in this study, was toxic to the seed or responsible for delayed emergence, as reported by Nyborg (1961).

The control treatment in the frozen set yielded 10.2 g.pot^{-1} and yield was increased by all treatments (Table 45). However differences were significant only with MAP plus urea broadcast (treatment 11), MAP plus ammonium sulphate dual banded (treatment 5); and separate bands of MAP plus ammonium nitrate (treatment 4). Separate bands of ammonium nitrate and MAP were superior to dual or separate bands of MAP and urea, but equal to either band placement of MAP plus ammonium sulphate and dual bands of MAP plus ammonium nitrate. Phosphorus uptake in the frozen set was significantly increased compared to the control with dual bands of ammonium sulphate (treatment 5), and MAP and urea broadcast (treatment 11). No differences were apparent among other treatments. In the frozen set, Pdff ranged from 6.3 to 10.4 mg.pot^{-1} and was greatest when MAP and ammonium sulphate were placed in a dual band. For treatments where P was banded differences in Pdff could not be correlated to specific effects of N carrier or P placement.

In general terms, yield response to treatments could be ranked in descending order as follows: broadcast applications of MAP and urea > seed row P and broadcast urea > dual or separate bands of MAP and

Table 45. Effect of Treatment on Dry Matter Production, Phosphorus Uptake and Total Pdff of Barley in Frozen Set in Pot Study A

	Treatment			Yield	P uptake	Total Pdff
	P	N	Placement	(g.pot^{-1})	(mg.pot^{-1})	(mg.pot^{-1})
1.	MAP,	urea,	dual	11.0 bc	24.9 c	6.3 c
2.	MAP,	urea,	separate	10.8 bc	27.5 bc	8.3 abc
3.	MAP,	A.N.,	dual	11.9 abc	28.4 bc	7.6 bc
4.	MAP,	A.N.,	separate	12.7 a	30.5 bc	8.6 ab
5.	MAP,	A.S.,	dual	12.2 ab	32.5 b	10.4 a
6.	MAP,	A.S.,	separate	11.4 abc	27.5 bc	8.6 ab
7.	0 P,	urea,	band	10.2 c	24.7 c	-----
9.	MAP band;	urea broadcast		11.1 bc	28.3 bc	8.2 bc
11.	MAP,	urea,	broadcast	12.8 a	40.0 a	----

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

ammonium nitrate or ammonium sulphate > dual or separate bands of MAP and urea > controls. Urea as a nitrogen carrier, when placed in a dual band with MAP, generally resulted in lower yield, lower P uptake and lower total Pdff than similar placement with other N fertilizers. This may be due to differences in pH near the application site of urea and ammonium sulphate. Studies by Pang et al (1973) showed that banded ammonium sulphate lowered the local pH, where as urea increased the local pH initially. It is possible that the increased pH surrounding a urea band, in combination with soil carbonates, resulted in calcium phosphate precipitation, and rendered the P less available to the plant. Toews and Soper (1978) have shown barley yield increases to be greater with NH_4NO_3, drilled or incorporated, than urea. Similar effects have been noted by Olson and Drier (1956) and Leonce and Miller (1966). The presence of NH_4^+ compared to other ions has had the greatest effect on fertilizer P absorption by causing a drop in pH within the rhizosphere. With respect to the other N carriers, while differences were not significant, separate bands of MAP and ammonium nitrate were superior to dual, and dual bands of ammonium sulphate and MAP were superior to separate bands, but only in the frozen set. Field studies with barley in Southern Alberta by Kucey (1986) have shown little difference between urea, ammonium nitrate and anhydrous ammonia when banded as nitrogen sources. Reasons for the similarity of the effect of different carriers on barley were not explained.

Differences between carbonated and noncarbonated soils with respect to yield, P uptake and total Pdff were large. Yield and nutrient uptake were significantly greater on the noncarbonated soil than the carbonated soil in the nonfrozen set (Table 46). Total phosphorus derived from the fertilizer on the noncarbonated soil was almost double the total Pdff value on the carbonated soil for the nonfrozen set. However amount of soil P taken up was very similar between the two soils. Yield and nutrient uptake was also significantly greater on the noncarbonated soil than the carbonated soil in the frozen set (Table 47). Total Pdff was increased from 7.1 $mg.pot^{-1}$ on the carbonated soil to 9.5 $mg.pot^{-1}$ on the noncarbonated soil. This is consistent with studies by Lewis and Racz (1969), who found that the rate and extent of P movement from a pellet site is greater in noncalcareous soils than calcareous. They found that high pH and large amounts of Ca and Mg in the calcareous soil resulted in rapid precipitation of P close to the pellet site. On the other hand, the lower pH, and smaller amounts of Ca and Mg in the noncalcareous soil reduced the amount of precipitation, resulting in increased P availability to the plant, and greater Pdff.

The results obtained for each treatment on each soil are given in Tables 48 and 49. Analysis of variance conducted on treatment means, P uptake means, and Pdff means showed no significant interactions between treatment and soil.

In summary, while few significant differences were apparent, broadcast P and seed row P treatments were superior methods of phosphorus placement to band applications. Differences between N carriers were small but ammonium nitrate and ammonium sulphate did produce more dry matter of barley than urea at the 53 day harvest date. The lack of significant differences between N carriers may be explained

Table 46. Effect of Soil Carbonates on Dry Matter Production, Phosphorus Uptake and Total Pdff of Barley in Nonfrozen Set in Pot Study A

	Yield ($g.pot^{-1}$)	P uptake ($mg.pot^{-1}$)	Total Pdff ($mg.pot^{-1}$)
Soil Carbonates			
Noncarbonated	9.2 a	30.0 a	10.8 a
Carbonated	8.3 b	24.0 b	5.8 b

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Table 47. Effect of Soil Carbonates on Dry Matter Production, Phosphorus Uptake and Total Pdff of Barley in Frozen Set in Pot Study A

	Yield ($g.pot^{-1}$)	P uptake ($mg.pot^{-1}$)	Total Pdff ($mg.pot^{-1}$)
Soil Carbonates			
Noncarbonated	11.9 a	30.6 a	9.5 a
Carbonated	11.2 b	28.1 b	7.1 b

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Table 48. Effect of Treatment x Soil Interaction on Dry Matter Production, Phosphorus Uptake and Total Pdff of Barley in Nonfrozen Set in Pot Study A

Treatment P N Placement	Soil*	Yield (g.pot^{-1})	P uptake (mg.pot^{-1})	Total Pdff (mg.pot^{-1})
1. MAP, urea, dual	C	7.6	22.3	4.3
	NC	9.0	30.1	7.8
2. MAP, urea, separate	C	8.2	23.2	6.5
	NC	8.2	27.8	9.4
3. MAP, A.N., dual	C	7.8	22.1	5.4
	NC	9.0	28.9	10.6
4. MAP, A.N., separate	C	8.5	24.5	6.1
	NC	9.4	31.1	11.5
5. MAP, A.S., dual	C	8.8	23.8	3.8
	NC	9.1	28.6	10.3
6. MAP, A.S., separate	C	8.6	26.8	5.6
	NC	9.4	31.1	10.7
7. 0 P, urea, band	C	8.4	20.9	-----
	NC	8.0	21.6	-----
8. 0 P, urea, broadcast	C	8.0	20.3	-----
	NC	8.4	22.5	-----
9. MAP band; urea broadcast	C	8.7	24.7	6.5
	NC	9.5	30.5	10.7
10. MAP seed row; urea broadcast	C	9.1	26.7	8.2
	NC	9.7	32.2	15.2
11. MAP, urea, broadcast	C	8.3	29.0	-----
	NC	11.2	43.5	-----
		NS	NS	NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*Refers to Soil Carbonates: C = Carbonated, NC = Noncarbonated

Table 49. Effect of Treatment x Soil Interaction on Dry Matter Production, Phosphorus Uptake and Total Pdff of Barley in Frozen Set in Pot Study A

Treatment				
P N Placement	Soil*	Yield (g.pot^{-1})	P uptake (mg.pot^{-1})	Total Pdff (mg.pot^{-1})
1. MAP, urea, dual	C	10.7	24.2	6.1
	NC	11.3	25.6	6.4
2. MAP, urea, separate	C	10.9	26.0	7.3
	NC	10.7	29.0	9.4
3. MAP, A.N., dual	C	11.6	28.5	6.8
	NC	12.1	28.3	8.5
4. MAP, A.N., separate	C	12.0	28.7	6.6
	NC	13.4	32.3	10.6
5. MAP, A.S., dual	C	11.3	34.3	9.0
	NC	13.1	30.7	11.9
6. MAP, A.S., separate	C	11.5	24.5	6.5
	NC	11.3	30.5	10.6
7. 0 P, urea, band	C	10.5	24.5	-----
	NC	10.0	25.0	-----
9. MAP band; urea broadcast	C	10.1	27.4	7.2
	NC	12.0	29.1	9.3
11. MAP, urea, broadcast	C	11.9	34.7	-----
	NC	13.6	43.3	-----
		NS	NS	NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

*Refers to Soil Carbonates: C = Carbonated, NC = Noncarbonated on the basis of restricted root growth due to pot size, and possible dispursement of banded fertilizer due to constant watering and maintenance of moisture content at field capacity. Monoammonium phosphate, in both the frozen and nonfrozen sets, remained more available on the noncarbonated soil compared to the carbonated soil. This was attributed to greater precipitation of calcium or magnesium phosphates on the carbonated soil due to high amounts of Ca and Mg present.

7. Pot Study B

7.1 The Effect of Phosphorus Placement and Freeze Treatment on Dry Matter Production and Phosphorus Recovery by Barley using ^{32}P

7.1.1 Introduction

Results from the previous studies showed that seed row placement and broadcast applications of P were more effective in increasing barley yield than band placement. There was little difference in the effect of urea, ammonium sulphate, or ammonium nitrate on barley yield, P uptake or Pdff. However, yield, P uptake and Pdff were more effectively increased on the noncarbonated soil than on the carbonated soil indicating that P fertilizer remained available longer on noncarbonated soils. The effect of freezing and thawing on fertilizer effectiveness could not be adequately evaluated. It was therefore necessary to conduct a second pot experiment to evaluate the effect of freezing and thawing of soil and fertilizer on barley yield and phosphorus recovery. In this study, all treatments were evaluated simultaneously in an environmentally controlled chamber. The study involved band, broadcast and seed row placements of ^{32}P labelled MAP and urea.

7.1.2 Material and Methods

Soil was collected from the top 15 cm of a carbonated silty clay soil of the Gervais Series. Characteristics are given in Table 50.

Table 50. Characteristics of Soil Used in Pot Study B

Classification	Gleyed Cumulic Regosol
Series	Gervais SiC
NO_3-N (ppm to 15 cm depth)	7.6
$NaHCO_3$ extractable P (ppm to 15 cm depth)	7.6
NH_4OAc extractable K (ppm to 15 cm depth)	345
SO_4-S (ppm to 15 cm depth)	10+
pH (in water)	7.4
$CaCO_3$ equivalent (%)	20.2
Conductivity ($dS.m^{-1}$ to 15 cm depth)	0.5

The soil was low in extractable NO_3-N and P, and high in exchangeable K and water soluble SO_4-S. The study was set up as a 4 x 2 factorial experiment employing a randomized complete block design and allowed for concurrent evaluation of the effect of freezing and thawing on fertilizer effectiveness as well as the effect of fertilizer placement on barley yield. The experiment consisted of a frozen and a nonfrozen set of treatments. Each set included four methods of phosphorus placement as given in Table 51. Each treatment was replicated three times. Soil preparation, fertilizer application, freezing, seeding and harvest procedures were the same as outlined in Section 6.1.2.

Light conditions in the growth chamber were set at 15 hours daylight and 9 hour darkness. Day and night temperature was controlled at 21°C and 16°C respectively.

Table 51. Treatments Applied in Pot Study B

	P Placement	N Placement
1.	control (0 P)	urea banded
2.	MAP seed row	urea banded
3.	MAP dual bands	urea dual bands
4.	MAP separate bands	urea separate bands

Basic Fertilizer Rate: 25 ppm P, 50 ppm N
P applied as MAP (11-55-0); N applied as urea (46-0-0)
Each treatment applied to frozen and nonfrozen sets

7.2 Results and Discussion

Data was analysed statistically using a 2 way analysis of variance. The effect of method of P placement was evaluated by combining data according to treatment, regardless of freezing. Effect of freezing and thawing was statistically analysed by evaluating frozen vs nonfrozen sets, regardless of method of P placement. A third analysis of variance was then conducted to determine if any interaction occurred between method of P placement and freezing.

Dry matter yields of barley were increased with the addition of phosphorus (Table 52). Yield response was greatest with seed row and dual band treatments, and was significantly greater than separate bands and the control. Dry matter yields of separate bands did not differ significantly from the control. It should be noted that all 3 replicates of treatment 4 (separate bands) in the frozen set produced very little dry matter. There was no obvious reason for this, but it does confound the data when averaging results from frozen and nonfrozen separate band treatments (9.7 $g.pot^{-1}$). In all likelihood, 9.7 $g.pot^{-1}$ does not represent a true estimate of dry matter production resulting from separate bands and perhaps should be disregarded. The apparent advantage of seed row placement over band placement is consistent with data from Pot Study A, where seed row placement of P resulted in higher yields than either dual or separate band placements and indicates that the crop's need for P at an early growth stage is best facilitated by close to the seed placement.

Phosphorus uptake was significantly increased over the control by

Table 52. Effect of N and P Placement on Dry Matter Production, Phosphorus Uptake and Total Pdff of Barley in Pot Study B

Treatment	Yield ($g.pot^{-1}$)	P uptake ($mg.pot^{-1}$)	Total Pdff ($mg.pot^{-1}$)
1. control (0P)	8.5 b	9.9 c	----
2. seed row	15.3 a	20.9 a	11.9 a
3. dual	12.9 a	16.1 b	7.8 b
4. separate	9.7 b	14.9 b	7.5 b

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Table 53. Effect of Freeze Treatment on Dry Matter Production, Phosphorus Uptake and Total Pdff of Barley in Pot Study B

Treatment	Yield ($g.pot^{-1}$)	P uptake ($mg.pot^{-1}$)	Total Pdff ($mg.pot^{-1}$)
Nonfrozen	12.3	17.0 a	10.4 a
Frozen	10.9	13.9 b	7.7 b
	NS		

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

all methods of P placement. Highest P uptake occurred with seed placed P, and was significantly greater than dual or separate band placements. Dual and separate bands of MAP and urea resulted in similar plant P uptake values, and were considerably greater than that of the control. Similarly, recovery of fertilizer P was significantly increased by seed row placement compared to band placement.

Subjecting soil and fertilizer to freezing and thawing resulted in lower, but not significantly different, yields compared to the nonfrozen treatments (Table 53). Phosphorus uptake and total phosphorus derived from fertilizer were significantly greater with nonfrozen treatments than frozen. This indicated that P applied at or near the time of seeding was more readily available than P which had been subjected to freezing. Accordingly, spring applied fertilizer is more available to growing plants than fall applied, and can result in greater recovery of P. Studies by Christianson and Cho (1979) indicated that during the freezing process, between 0 and -3.5°C, urea undergoes chemical denitrifcation at high rates, and results in large N losses. It is possible that changes also occur with phosphorus fertilizer in the same temperature range. Soil water content at the freezing front is high, and changes in P solubility could occur, or perhaps changes occurring with nitrogen affect P availability.

Large differences in dry matter production, P uptake, and total Pdff were apparent with respect to an interaction between N and P placement and freezing (Table 54). Seed placed P (treatment 2) in both the frozen and nonfrozen sets produced equivalent yields, P uptake and total Pdff values. This could be expected as phosphorus was not

Table 54. Effect of N and P Placement x Freeze Treatment Interaction on Dry Matter Production, Phosphorus Uptake and Total Pdff of Barley in Pot Study B

Treatment	Yield ($g.pot^{-1}$)	P uptake ($mg.pot^{-1}$)	Total Pdff ($mg.pot^{-1}$)
1. control, nonfrozen	7.8 bc	9.4 bc	----
control, frozen	9.2 b	10.5 bc	----
2. seed row, nonfrozen	15.8 a	22.7 a	13.9 a
seed row, frozen	14.8 a	19.2 a	9.9 a
3. dual, nonfrozen	10.6 b	13.8 b	4.6 b
dual, frozen	15.2 a	18.4 a	10.4 a
4. separate, nonfrozen	14.8 a	22.1 a	12.7 a
separate, frozen	4.6 bc	7.7 c	3.0 b

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

frozen. Seed placed P was applied at the time of seeding, thus only urea was actually frozen. However, if urea was denitrified in the temperature range of $0^{o}C$ and $-3.5^{o}C$, resulting in N losses, as suggested by Christianson and Cho (1979), it did not affect barley yields in this study.

Dual bands of N and P proved to be more efficient in increasing dry matter production, total P uptake and total phosphorus derived from fertilizer when frozen than nonfrozen. Yields of frozen dual bands were similar to seed row placement. As noted earlier separate bands in the frozen set performed poorly, and this could not be explained. Separate bands of N and P, nonfrozen, resulted in yields equal to frozen dual bands. Reasons for the discrepancies between the effect of freezing on dual and separate bands are unclear.

In summary, P placed with the seed produced equal to or greater yield, P uptake and Pdff than band treatments. Results of other placements, and freeze treatment simulating fall field application, are inconclusive. This indicated that freezing of soil and fertilizer in pots for a short period of time has either no effect on soil and fertilizer or it is not a good simulation of over winter freezing in the field. Actual freezing in the field would be different than a simulated pot experiment because soil in a field situation does not only freeze once, but undergoes constant freezing and thawing during late fall. This could allow greater opportunity for changes to occur with N or P fertilizers.

8. Field Study 3

8.1 The Effect of Nitrogen Carrier on Yield and Phosphorus Recovery by Canola and Flax

8.1.1 Introduction

In Pot Study A (Section 6), the effect of nitrogen carrier on yield and phosphorus recovery of barley was evaluated in a pot experiment. Results indicated a small yield advantage to using ammonium sulphate or ammonium nitrate rather than urea, but P uptake results were difficult to interpret. It was therefore decided to conduct a field study to further evaluate the effect of nitrogen carrier on yield and phosphorus recovery by canola and flax.

8.1.2 Material and Methods

The study was conducted at the same time as Study 2 on the same silty clay soil of the Gervais series. Soil characteristics are given in Table 34. Extractable soil P was very low (5.0 $kg.ha^{-1}$ to 15 cm depth), NO_3-N level was high and the soil was high in carbonates.

Two separate blocks were established, one for flax and the other for canola. A randomized complete block design was set up with 6 treatments and 4 replicates (Table 55). Treatment plots consisted of 8 seed rows (17.8 cm spacing) 7.6 m long. Treatments consisted of dual band placements of monoammonium phosphate at 20 $kg.ha^{-1}$ P with urea, ammonium nitrate, nitrogen solution, or aqua NH_3 at 50 $kg.ha^{-1}$ N.

Table 55. Treatments Applied in Study 3

P Carrier	N Carrier
1. MAP (control)	0 N
2. MAP (11-55-0)	urea (46-0-0)
3. MAP	ammonium nitrate (34-0-0)
4. MAP	nitrogen solution (28-0-0)
5. MAP	aqua NH_3 (20-0-0)
6. TSP (0-45-0)	urea

All treatments dual banded
Basic Fertilizer Rate: 20 $kg.ha^{-1}$ P, 50 $kg.ha^{-1}$ N

Although MAP is the phosphate fertilizer most widely used in Western Canada, a triple super phosphate and urea treatment was also included, because MAP has been shown to be a more effective source of P than TSP (Dion et al, 1949b; Mitchell, 1957). Fertilizer was spring applied using a deep bander with 5 cm wide chisel points. All fertilizer was dual banded to a 10 to 12 cm depth, and spaced 40 cm apart. Following banding, the plot was harrowed twice using a spike harrow to prepare a firm, even seedbed. At this time the soil was quite wet below the surface and some problems were experienced with the bander plugging. This resulted in substantial soil disturbance.

Canola (_Brassica napus_ var Regent) and flax (_Linum usitatissimum_ var Dufferin) were seeded at 7 and 40 $kg.ha^{-1}$ respectively, parallel to fertilizer bands using an 8 run double disc seeder. The plot had patches of wild oats and Canada Thistle, but these weeds were controlled using recommended herbicides.

Canola and flax were sampled 40 and 47 days after seeding, respectively for total above ground yield and nutrient analysis. The harvest area was 4 rows x 0.61 m (0.43 m^2). At maturity, 4 rows x 6.1 m (4.3 m^2) of the flax plot was harvested for yield and nutrient analysis. The canola plot was not harvested as it was inadvertently destroyed prior to final harvest.

8.2 Results and Discussion

8.2.1 Introduction

At time of seeding, surface soil was dry, but subsurface moisture reserves were good. Canola and flax germinated and emerged evenly. Adequate precipitation was received throughout the growing season, and the crops did not experience moisture stress at any time.

8.2.2 Canola

Midseason dry matter yields of canola were variable, and ranged from 1051 to 1715 kg.ha^{-1} (Table 56). Yield increased significantly in response to N fertilization only with MAP plus urea application (treatment 2). The application of N solution or aqua NH_3 plus MAP reduced yields compared to MAP alone but differences were not significant. The yield increase associated with urea or ammonium nitrate application compared to MAP alone, and a yield decrease with N solution or aqua NH_3 is not understood. Considering that depressed yields were in both cases associated with liquid fertilizer, it is possible that there was a problem with quantity output by the pump which was used in application of the liquid fertilizers. Also, it is recommended in 1986 Field Crop Production Recommendations for Manitoba that "when using anhydrous ammonia and aqua ammonia apply no less than 5 days before seeding". This practice was not followed in this study as plots were seeded 2 days after fertilizer application.

Triple super phosphate and urea yielded significantly less than MAP and urea. The increased efficiency of MAP over TSP on calcareous soils is in agreement with research reported by other researchers (Dion et al, 1949b; Rennie and Soper, 1958; Miller and Ohlrogge, 1958; Leonce and Miller, 1966; Miller et al, 1970; Riley and Barber, 1971). Banding of ammonium in intimate association with fertilizer P has been shown to

Table 56. Midseason Dry Matter Production and Phosphorus Uptake ($kg.ha^{-1}$) and Concentration (%) in Canola in Study 3

Treatment	Yield	Phosphorus uptake	Phosphorus %
1. MAP, no N (control)	1322 b	6.0 ab	0.45 ab
2. MAP, urea	1715 a	6.7 a	0.39 b
3. MAP, A.N.	1415 ab	5.8 ab	0.41 b
4. MAP, N solution	1086 b	5.5 ab	0.51 a
5. MAP, aqua NH3	1051 b	4.0 b	0.38 b
6. TSP, urea	1097 b	4.0 b	0.36 a

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Table 57. Midseason Dry Matter Production and Phosphorus Uptake ($kg.ha^{-1}$) and Concentration (%) in Flax in Study 3

Treatment	Yield	Phosphorus uptake	Phosphorus %
1. MAP, no N (control)	1293	2.3	0.18
2. MAP, urea	1478	2.8	0.19
3. MAP, A.N.	1241	2.3	0.19
4. MAP, N solution	1316	2.4	0.18
5. MAP, aqua NH3	1299	2.3	0.18
6. TSP, urea	1120	2.2	0.20
	NS	NS	NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

result in a drop in pH in the fertilizer-soil reaction zone due to the release of H^+ ions by roots upon uptake of ammonium. This decrease in pH is associated with an increase in P solubility, and results in increased P uptake. The beneficial effect of NH_4^+ on P solubility is essentially "built-in" to MAP, as opposed to TSP. It should be noted that a large visual response to MAP was apparent in the field, indicating a definite advantage to MAP over TSP. Final yield was not determined as the plot was inadvertently destroyed prior to harvest.

Phosphorus uptake at midseason harvest by canola ranged from 4.0 to 6.7 $kg.ha^{-1}$. All treatments, except treatment 2, resulted in lower P uptake than the control. The uptake data is consistent with the yield data, in that urea is the superior N source to ammonium nitrate, nitrogen solution and aqua NH_3. However, it is inconsistent with the previous study (Pot Study A) where urea was inferior to the other N carriers. Phosphorus concentration within the plant ranged from 0.36 % to 0.51 %, the lowest uptake associated with the TSP treatment. Monoammonium phosphate and ammonium nitrate resulted in significantly greater P concentration than all other treatments except the control. Phosphorus concentration in the control was greater than the other treatments, but not significantly.

8.2.3 Flax

There was no significant effect of N carrier on yield and P uptake of flax at midseason (Table 57). Monoammonium phosphate plus urea produced the highest yield (1478 $kg.ha^{-1}$) while TSP plus urea produced the lowest yield (1120 $kg.ha^{-1}$). This data again indicates that MAP is a superior phosphate carrier to TSP (Dion et al, 1949b).

Phosphorus uptake ranged from 2.2 kg.ha^{-1} (TSP plus urea treatment) to 2.8 kg.ha^{-1} (MAP plus urea) and was not significantly affected by nitrogen carrier. Similarly, P concentration remained constant among treatments.

Final flax grain yields increased with the application of N fertilizer compared to the control, but differences were not significant (Table 58). Yield ranged from 706 kg.ha^{-1} (MAP alone) to 818 kg.ha-^{1} (MAP plus ammonium nitrate). The apparent advantage of MAP plus urea over other treatments at midseason was not evident at final harvest.

Total P uptake was not significantly affected by treatment, although it ranged from 3.1 kg.ha^{-1} in the control, and TSP plus urea treatments up to 3.8 kg.ha^{-1} with MAP plus ammonium nitrate, or MAP plus nitrogen solution. Percent P ranged from 0.43 to 0.47 %, and differences were not significant. This data indicates that either flax is a poor utilizer of banded P as suggested by Racz et al (1965), Kalra and Soper (1968) and Strong and Soper (1973) or soil P levels were adequate prior to fertilization.

8.2.4 Summary

In summary, dry matter production of canola responded well to band application of MAP and urea, and yields and P uptake were increased above that produced by dual bands of MAP with ammonium nitrate, aqua NH_3 or N solution. Monoammonium phosphate banded alone, or with urea or ammonium nitrate resulted in higher yields and P uptake than TSP.

Table 58. Final Yield and Phosphorus Uptake (kg.ha^{-1}) and Concentration (%) in Flax in Study 3

Treatment	Yield	Phosphorus	
		uptake	%
1. MAP, no N (control)	706	3.1	0.44
2. MAP, urea	793	3.7	0.47
3. MAP, A.N.	818	3.8	0.46
4. MAP, N solution	810	3.8	0.47
5. MAP, aqua NH3	785	3.5	0.45
6. TSP, urea	726	3.1	0.43
	NS	NS	NS

Values within a column followed by the same letter are not significantly different at p=.05 (Duncan's Multiple Range Test).

Flax showed little response to applied P regardless of N fertilizer. Yield and % P within the plant were similar among fertility treatments.

9. Summary and Conclusions

The results from field studies 1 and 2 indicate that yields of barley and rapeseed are increased with the addition of phosphorus when grown on phosphate deficient soils. Both crops respond well to the placement of P, either all or in part, with the seed. Rapeseed also appeared to favor 20 cm spaced dual bands of N and P in one study, but preferred seed row or broadcast P applications in a second study. Although not always the case, barley responded to broadcast P application up to rates of 242 $kg.ha^{-1}$. However 100 $kg.ha^{-1}$ N spring broadcast in addition to 100 $kg.ha^{-1}$ N plus 22 $kg.ha^{-1}$ P dual banded, resulted in depressed dry matter production early in the season. Rapeseed, on the other hand, responded to banded P applied at 22 $kg.ha^{-1}$, and yield did not increase further with higher rates of application. This indicated that perhaps rapeseed has a greater ability to exploit the nutrients available in the soil than barley. Response of barley to fall vs spring applied dual N-P bands was variable and inconclusive. Flax yield and nutrient recovery were unaffected by the addition of fertilizer P, and flax would appear to be a more efficient utilizer of soil P.

A pot experiment was conducted to evaluate the effect of nitrogen carrier and phosphorus placement on barley yield and nutrient recovery on carbonated and noncarbonated soil. In general, broadcast or seed row P with urea was more efficient in increasing yield than band placements of MAP with urea, ammonium sulphate, or ammonium nitrate. Phosphorus placed with the seed was the only treatment which increased total phosphorus derived from fertilizer in the plant. Barley yields and phosphorus recovery were greater on the noncarbonated soil than on the carbonated soil, likely due to less precipitation of phosphorus with calcium or magnesium on the noncarbonated soil resulting in phosphorus remaining available longer.

A second pot experiment evaluated the effect of fall and spring applied phosphorus on yield and P recovery under simulated conditions. This study again concluded that seed row P is a superior treatment to band P placement, although not always significantly so. With respect to the timing of application, results were inconclusive.

The results of the first pot experiment led to the initiation of a field trial to investigate various N carriers, and their effect on yield and nutrient recovery by canola and flax. Midseason canola production and P recovery was higher when fertilized with MAP and urea, rather than ammonium nitrate, nitrogen solution or aqua NH_3. Monoammonium phosphate as a P source was markedly more efficient in improving yield than TSP. Once again, flax yield and P uptake was not affected by N carrier or applied P.

In general, response to applied P was inconsistent and it is difficult to draw definite conclusions. The lack of consistent response to phosphorus fertilization could be attributed to several factors. Plants are very subject to the harmful effects of temperature extremes and conditions of moisture stress. Growing conditions in 1982 were good with respect to moisture and temperature, but in 1983, extended periods of high temperature were experienced, resulting in province wide yield depression. Also, the soils used in these studies were determined to be P deficient by standard soil test procedures. However, in some cases, response to applied P was minimal. It should be recognized that there are limitations to the accuracy of soil tests, and other factors, such as management practices and history of fertilization should be considered in site selections.

An overall view of all studies indicates that placement of phosphorus in the seed row would seem to be the best placement for increasing barley and canola yields. However, bands often performed as well as seed row placement, particularly at final harvest. High rate applications of N or P were not efficient in increasing yields consistently, and flax yields were reduced with high rate fertilization. With respect to fertilizers as nutrient carriers, little difference was found between urea, ammonium sulphate or ammonium nitrate in their effect on yield and P recovery by barley, flax or canola. Monoammonium phosphate, however, was definitely a superior source of P to the plant compared to triple super phosphate. Monoammonium phosphate was more efficiently utilized when applied to a noncalcareous soil than to a carbonated soil.

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APPENDIX 1

A. Analysis of Variance for Barley Grain at the Middleton Site in Study 1A

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F value
Replicate	5	4689361		1.53*
Treatment	4	1809437		0.74
Error	20	12233886	611694	
Total	29	18732684		

Coefficient of Variation 19.91

B. Analysis of Variance for Barley Grain at the Middleton Site in Study 1B

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F value
Replicate	5	9391944		5.33*
Treatment	4	3377849		5.92*
Error	10	3171662	317166	
Total	19	15941455		

Coefficient of Variation 16.22

C. Analysis of Variance for Barley Grain at the Middleton Site in Study 1C

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F value
Replicate	5	3885791		1.23*
Treatment	3	2082320		1.38*
Error	15	8463522	564235	
Total	23	14431633		

Coefficient of Variation 21.75