

**EFFECT OF NITROGEN AND PHOSPHORUS PLACEMENT ON
TIME OF PHOSPHORUS UPTAKE AND YIELDS OF CANOLA AND FLAX**

by

Leonard S. Nafuma

A thesis
presented to the University of Manitoba
in partial fulfillment of the
requirements for the degree of
Master of Science
in
Department of Soil Science

Winnipeg, Manitoba

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ABSTRACT

Two field and two growth bench experiments with canola and flax were conducted from 1984-1986 to study the effect of N and P placement on yield and phosphorus accumulation. Nitrogen placement methods included deep banding, and broadcast and incorporated applications. Phosphorus applications included placement with the seed or placement away from the seed in different positions. Results from the first field experiment were not significantly affected by various N-P placement combinations in terms of yield and phosphorus accumulation. This may have been due to low yields and high deviations from the mean caused by severe weather and growing conditions.

The first growth bench experiment showed that mixing phosphorus with the soil resulted in low fertilizer phosphorus recovery by canola compared to sidebanding phosphorus close to the seed (2.5 cm below x 2.5 cm to the side). There was a delay in phosphorus absorption where nitrogen and phosphorus were sidebanded together close to the seed or where the two elements were dual sidebanded (10 cm x 10 cm) away from the seed. Highest fertilizer recovery was observed where nitrogen and phosphorus were separately sidebanded (2.5 cm x 2.5 cm) close to the seed. There was no nitrogen source (urea or ammonium nitrate) effect on dry matter production or phosphorus accumulation. Also, urea sidebanded together with phosphorus did not influence dry matter production or phosphorus accumulation. Generally phosphorus application significantly

increased dry matter production, fertilizer and total phosphorus accumulation. Among the dual placements of urea and phosphorus, placement 2.5 cm directly below the seed row resulted in lowest dry matter production, fertilizer and total phosphorus accumulation.

The second field experiment showed response to phosphorus placed with the seed in terms of seed yield and total phosphorus accumulation for canola. Also, canola plants in plots where phosphorus was placed with the seed recovered higher amounts of fertilizer phosphorus compared to other phosphorus treated plants. Flax, however, responded to phosphorus placed with the seed in terms of dry matter production and total phosphorus accumulation but this response was not reflected in seed yield. Flax plants also recovered more fertilizer phosphorus where phosphorus was placed with the seed compared to other placement methods. There was no marked effect of nitrogen deep banded together with phosphorus in terms of yield and total phosphorus accumulation.

Second growth bench experiment in the greenhouse conducted with flax and using ^{32}P tracer technique showed that the plants recovered more fertilizer phosphorus where phosphorus was placed with the seed compared to where it was sidebanded close (2.5 cm x 2.5 cm) to the seed or away (10 cm x 10 cm) from the seed row. There was, however, no significant response in terms of dry matter production and total phosphorus accumulation to applied phosphorus.

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Chapter I

INTRODUCTION

Phosphorus is one of the major elements essential for plant growth. It is taken up by plants in relatively small amounts compared to nitrogen and potassium and its presence in the plant is fundamental because of its unique functions which cannot be performed by any other element.

Placement technology, which complements and updates fertilization recommendations, has rapidly developed in numerous cropping systems in recent years. Fertilizer economics and efficiencies have dictated a major advancement in fertilizer placement in the 1980s. This has been prompted by increasing costs of energy and fertilizers, especially phosphate fertilizers whose chemical interactions with the soil has been shown to tend towards decreased availability of the element to plants depending on the soil type. In acid soils, phosphorus chemically reacts with aluminum and iron to form relatively insoluble compounds of the element or can be physically adsorbed on the surfaces of the hydrous oxides of Al and Fe, which makes it unavailable to plants. Similarly, in calcareous soils which dominate a large area in Manitoba, phosphorus reacts with calcium and magnesium to form calcium and magnesium phosphates which are relatively insoluble and become localized in the region of application. This contributes to the relative immobility of phosphorus in the soil system which constitutes one of its unique characteristics and necessitates precise placement of the element in the

soil so that it can be efficiently taken up by plants, particularly during early stages of plant growth. The uptake of nutrients by plants depends on a variety of factors including: solubility of the fertilizer source; method of placement; soil pH (Hagen and Hopkins, 1955; Hendrix, 1967), temperature, soil type (texture and chemical composition), type of plant species, P requirement of the plant (Racz et al., 1965) plant root morphology and distribution.

Previous work in Manitoba has generally shown that cereal crops growing on phosphorus deficient soils will respond well to phosphorus fertilizer particularly if it is placed with the seed (Bailey, 1979). Walker (1980) in Alberta reported similar results. Canola has also been shown to respond well to applied phosphorus when low rates are applied with the seed or when phosphorus is broadcast and incorporated at higher rates on phosphorus deficient soils. Flax has generally been unresponsive to applied phosphorus even on soils testing low in extractable phosphorus. Rogalsky and Ridley (1983), conducted field trials with phosphorus placement for flax and canola¹. In those studies phosphorus was placed: with the seed, below the seed, broadcast and incorporated, and in deep wide bands. In some treatments nitrogen was also applied with the phosphorus to ascertain if nitrogen fertilizer would affect the availability of applied phosphorus. Results were inconsistent because of severe weather and high soil phosphorus levels but in general canola responded best with phosphorus placed with the seed and flax did not respond. Since farmers are striving to reduce costs of fertilizers and their application, and since previous data was

¹ Personal communication, A.O. Ridley, Department of Soil Science

inconclusive studies with phosphorus placement were continued in this investigation. Particular emphasis was placed on phosphorus placement for canola and flax and the time required for the crops to show the fertilizer phosphorus was being taken up. Studies involved field trials in which yield and phosphorus accumulation was determined (using the difference method) and greenhouse experiments in which fertilizer phosphorus accumulation was monitored using ^{32}P tracer technique.

Chapter II

LITERATURE REVIEW

2.1 THE FUNCTIONS OF PHOSPHORUS IN PLANT GROWTH

Although absorbed in small amounts compared to nitrogen and potassium, phosphorus is one of the major essential elements in plant growth. The primary functions of phosphorus, which cannot be performed by any other element, range from energy transfer mechanisms to reproduction and encoding of genes. / Without adequate supply of phosphorus plants cannot attain their maximum growth potential, nor can they complete their normal reproductive process.

Green plants are unique among living organisms because of their capability to transform radiant energy into chemical energy. The energy absorbed during photosynthesis or released during respiration or anaerobic carbohydrate breakdown is utilized in the synthesis of the pyrophosphate bond in Adenosine triphosphate (ATP). This is the form in which the energy is conveyed to various processes such as active ion uptake and the synthesis of various organic compounds. Phosphorus is known to stimulate a number of physiological and biochemical processes such as translocation of assimilates (Walker, 1980), and starch synthesis and degradation (Preiss and Levi, 1979). A reduction in protein synthesis and nucleic acids frequently accompanies phosphorus deficiency (Martinovic, 1968). Goring (1979) in a study with corn observed

that protein levels of shoots and roots were reduced by 20 % at the end of one week of growth in a phosphorus deficient medium.

Within the tissues of most higher plants the major proportion of phosphorus is present in the form of inorganic phosphate (Mengel and Kirkby, 1978). A small proportion of this phosphorus is actively involved in metabolism, constantly recycling in processes such as ATP generation and utilization (Loughman, 1960). Under conditions of phosphorus sufficiency the major fraction of the inorganic phosphorus in the plant is non-metabolic, located within the vacuole. In seeds phosphorus is stored as phytic acid, the hexaphosphate of inositol. The inorganic phosphorus in the vacuole and the hexaphosphate of inositol in the seed are reserves and buffer the plant against immediate deleterious effects of phosphorus deficiency. Through chemical analyses of oat grain and spinach leaves, Michael (1939) observed that under conditions of phosphorus deficiency, seed and vacuole phosphorus were the first to decline while metabolic phosphorus levels remained essentially constant.

The effect of phosphorus on photosynthesis has been documented but not very consistently. Moderate phosphorus deficiency has been observed to cause reduction in photosynthesis in clover (Bouma, 1967), in spinach (Bottril et al., 1970), in sugar beets (Terry and Ulrich, 1973), in wheat (Cartwright et al., 1974) and in tobacco (Kakie, 1979). However, using leaf gas exchange and isolated chloroplast techniques, Terry (1976) observed that deficiency of phosphorus had a relatively small effect on photosynthesis in hydroponically cultured sugar beets. Tombesi (1969) using sugar beet and Watanabe (1970) using rice leaves have

demonstrated that ATP and NADPH generation is reduced in chloroplasts isolated from phosphorus deficient plants.

Adequate phosphorus nutrition has been found to improve water utilization; there is a reduction in transpiration rates associated with adequate phosphorus utilization (Williams, 1935). Also, rapid shoot growth results in better soil coverage thus reducing evaporation from the soil surface (Nelson, 1978).

2.2 PLANT ABSORPTION OF PHOSPHORUS AND TRANSLOCATION

It is beyond the scope of this manuscript to review the various soil phosphorus forms and the interrelationship between them. However, from the viewpoint of plant nutrition, three main soil phosphorus fractions that are important are (1) phosphorus in solution (2) phosphorus in the labile pool (exchangeable P) (3) phosphorus of the non-labile fraction (insoluble P).

Plants derive most of their phosphorus from the soil solution (Fried and Shapiro, 1961). Plant roots have the capability of absorbing phosphorus from solutions of very low phosphorus concentrations (Loneragan and Asher, 1967). Generally the phosphorus content of root cells and xylem sap is about 100 to 1000 fold higher than that of the soil solution. This indicates that phosphorus is taken up by plant cells against a very steep concentration gradient. Hence phosphorus uptake is an active process. Several researchers have studied the relationship between plant metabolism and phosphorus uptake and have observed

increased rates of phosphorus uptake associated with higher metabolic activity. Hai and Laudelout (1966) reported that an increased partial pressure of O_2 in the nutrient solution resulted in a higher phosphorus uptake rate in rice roots. Weigl (1967), working with Elodia Canadensis, found that P uptake was higher in light than under dark conditions. These findings suggest that respiratory carbohydrate metabolism drives the active phosphorus uptake process. Active uptake of phosphorus has been found to differ between plant species and even between cultivars of the same species. Barber and Thomas (1972) found considerable differences in the rate of phosphorus uptake by various maize (Zea mays L.) cultivars. The authors supposed that the capability of the plants to take up phosphorus was fixed genetically. Similar findings in P efficiency have been reported for genotypes of other crops including sorghum (Brown et al., 1977).

The rate of phosphorus uptake has been found to be pH dependent. Hagen and Hopkins (1955) in their study with barley plants reported that the plants were capable of absorbing both $H_2PO_4^{-1}$ and HPO_4^{-2} under aerobic conditions. However they pointed out that the concentration of HPO_4^{-2} in acid systems is low and could be of little importance in phosphorus absorption. Hendrix (1967) found that at pH 4, bean plants absorbed phosphorus at a 10 fold higher rate than at a pH of 8.7. Similar observations have been made by Hai and Laudelout (1966) who reported a maximum uptake rate by rice roots at pH 5.6. The rate of phosphorus uptake declined rapidly with increasing pH. Since this decrease followed the shift in the $H_2PO_4^{-1}:HPO_4^{-2}$ ratio in the nutrient solution, Hai and Laudelout (1966) supposed that only $H_2PO_4^{-1}$ and not HPO_4^{-2} is absorbed actively.

Phosphorus absorbed by plant cells has been found to rapidly become involved in metabolic processes. Loughman and Russell (1957) found that a significant proportion of absorbed labelled phosphorus was incorporated into organic compounds in less than one minute after entry into barley plants. Jackson and Hagen (1960) reported that after a period of only 10 mins. following uptake, 80% of the phosphorus absorbed was incorporated into organic compounds.

Phosphorus is readily mobile in the plant and can be translocated in an upward or downward direction. Clarkson et al. (1968) found that phosphorus taken up by basal root segments of barley plants was translocated to the root tip as well as to the upper plant parts. Young leaves are supplied not only with phosphorus taken up by the roots, but also with phosphorus originating from the older leaves (Bouma, 1967).

2.3 FACTORS AFFECTING SOIL PHOSPHORUS AVAILABILITY TO PLANTS

The availability of phosphorus compounds in soils depends on the form and solubility of the compounds and the nature of the soil environment, particularly the pH, kind and quantity of salts present and the plant species. With decreasing pH, iron and aluminum phosphates generally become less soluble, while calcium and magnesium phosphates increase in solubility (Pierre and Norman, 1953).

Although there is some evidence for contact feeding by roots of soil grown plants (Lehr and Brown, 1958), it is believed that plants obtain their phosphorus largely from the soil solution (Fried and Shapiro,

1961). Rate of phosphorus absorption from soil is controlled not only by the phosphorus concentration of the soil solution (the intensity factor), but also by the amount of solid phase phosphorus (the capacity factor), which is the amount of phosphorus in the solid phase released when the solution concentration declines (Islam, 1955; Barrow, 1966; Fried and Broeshart, 1967). The source of solution phosphorus is primarily the inorganic phosphorus compounds in the soil. As plants remove phosphorus, the solution concentration generally decreases. Soils differ in their capacity to release phosphate ion from the exchange (soil-solid phase) as the intensity becomes low around the roots. In many unfertilized soils, this rate of release is too slow to supply adequate phosphorus to the crop. However, in soils which contain labile fertilizer phosphorus, the rate of release into soil solution has been found to generally exceed the rate of uptake by plants (Olsen and Watanabe, 1966). Sadler and Stewart (1974) suggested that adsorbed phosphorus generally controls the concentration in the soil solution. Due to its relative immobility in soil, phosphorus absorbed by the plant is probably obtained from the thin layer of soil surrounding the root (Barber, 1962; Lewis and Qiurk, 1967).

Phosphorus absorption by soil grown plants are influenced by soil factors such as type of colloidal system (Graham, 1955), soil moisture (Dean and Gledhill, 1956; Fawcett and Quirk, 1960; Olsen et al., 1961; Beaton and Read, 1963) and an impedance factor which is dependent on the texture of the soil (Olsen and Watanabe, 1963). The latter two factors have been found to influence the diffusion of phosphorus to the plant root (Nye, 1968). The movement of phosphorus to the root surface for

soil grown plants is mainly by diffusion process (Bouldin and Black, 1954; Barber et al., 1963; Lewis and Quirk, 1967) and this has been found to occur within a few millimetres from the root surface (Olsen and Watanabe, 1963).

According to Bray (1954) the value of soil nutrients to plants is dependent upon their accessibility to roots and this is related to their mobilities in the soil. The author suggested that mobile nutrients are absorbed from the total soil volume containing roots whereas relatively immobile nutrients are absorbed from a thin layer of soil surrounding roots. Nye (1968) pointed out that the zone of nutrient depletion around a single root for phosphorus is small compared to the zone of depletion for either potassium or nitrate-nitrogen. The author suggested that when the depletion zone is very small the cylinder of root hairs surrounding the root plays a significant role in nutrient absorption.

Many researchers believe that the rate limiting step in phosphorus absorption is directly related to the internal metabolic system of the plant (Russell and Bishop, 1953; Hagen and Hopkins, 1955; Jackson and Hagen, 1959; Carter and Lathwell, 1967). Other workers have referred to a relationship between root surface area and rate of phosphorus absorption (Sommer, 1936; Jeffrey, 1967). Changes in pH at the root surface (Nye, 1968), competition with rhizosphere organisms for phosphorus (Bowen and Rovira, 1966; Barber and Loughman, 1967) and root exchange capacity (Drake and Steckel, 1955), are other plant factors which could possibly have influence on the rate of absorption by plant roots.

The influence of root exudate on the solubility of phosphorus in the rhizosphere has also been considered as a factor influencing the availability of soil phosphorus. It has been established that relatively large amounts of carbon assimilated in photosynthesis are released in the soil either through sloughage of root material or direct exudation (Hale and Moore, 1979). These organic materials are mainly chelating acids and may play a significant role in releasing phosphorus from the solid phase. This may occur through solubilization of relatively insoluble phosphate compounds like hydroxyapatite (Moghimi et al., 1978) or through exchange with surface bound phosphorus (Mengel and Kirkby, 1978).

2.4 FACTORS AFFECTING FERTILIZER PHOSPHORUS AVAILABILITY TO PLANTS

Availability of fertilizer phosphorus, like that of soil phosphorus, is influenced by a number of soil and plant factors. Studies conducted to evaluate the availability of various forms of phosphorus fertilizers (Dion et al., 1949; Bennett et al., 1954; Bouldin and Sample, 1959) showed that, in general their availabilities were related to their water solubilities.

Phosphorus fertilizers are commercially placed with the seed or banded away from the seed and in some cases broadcast and incorporated. Banding of phosphorus fertilizers away from the seed involves banding close to the seed or far away from the seed (deep banding). Response of a variety of crops to each of these methods of application of phosphorus fertilizers have been compared (Cooke, 1951; Cooke, 1954; Cooke et al.,

1956). Generally, in the early growth stages, crops extract more of their phosphorus from banded applications than from broadcast applications (Welch et al., 1949; Kalra and Soper, 1968). Kalra (1971), and Strong and Soper (1974a, 1974b) attributed this to extensive root proliferation within the fertilizer zone. However, the proportion of plant phosphorus derived from fertilizer in the later stages of growth has been found to be similar for both methods of application (Welch et al., 1949; Cooke, 1951; Cooke et al., 1956). On acid soils banded water soluble phosphorus fertilizer was found to be more available to several crops than broadcast applications (Speer et al., 1951; Rennie and Spratt, 1960; Mellado et al., 1962). Results obtained by the same authors, on calcareous soils, comparing the two methods of application of water soluble phosphorus fertilizers were variable. Mellado et al. (1962) found no difference between the two methods of phosphorus application. Other workers (Speer et al., 1951; Blanchar and Caldwell, 1965; Kalra and Soper, 1968), found less phosphorus utilization from banded than from broadcast application.

Bouldin and Sample (1958), and Starostka and Hill (1958) found that association of non-phosphorus containing salts increased the availability of various sources of applied phosphorus. Similar findings were reported by Rennie and Mitchell (1954), and by Ferguson and Hedlin (1963). The effect of high soluble salt concentration in enhancing the solubility of either the added source of phosphorus (Starostka and Hill, 1958) or its reaction products (Rennie and Mitchell, 1954), as well as an effect on the physiology of the plant (Olson and Dreier, 1956; Ferguson and Hedlin, 1963) were advanced to explain this effect.

The interaction of fertilizer phosphorus with the soil is another factor which influences its availability to plants. Due to its rapid precipitation with calcium and magnesium at high pH in calcareous soils, phosphorus applied in water soluble fertilizers has been observed to remain localized at the point of application (Heslep and Black, 1954; Lewis and Racz, 1969). Similar results were observed by Olsen and Flowerday (1971) when they reported that in alkaline or calcareous soils, soluble phosphorus compounds react with calcium to form less soluble dicalcium and tricalcium phosphates or apatite.

2.5 EFFECT OF NITROGEN ON PHOSPHORUS ABSORPTION BY PLANTS

2.5.1 Introduction

As early as 1939 it was observed that nitrogen in a fertilizer band enhanced phosphorus uptake by plants (Scarseth et al., 1942). Since then considerable research has been conducted on this phenomenon. The results that have been observed clearly indicate that the effect of nitrogen on phosphorus absorption is a general phenomenon in soil-plant systems. This has been found to occur with numerous crops and under widely varying soil and climatic conditions.

In field experiments in Indiana, Robertson et al. (1954) reported that absorption of banded fertilizer phosphorus by corn when nitrogen was included in the band was substantially greater than when the two fertilizers were applied separately. In Saskatchewan, Canada, similar results were obtained by Rennie and Mitchell (1954), and Rennie and Soper (1958) for wheat. In Nebraska, enhanced fertilizer phosphorus uptake by oats and wheat from a common band of nitrogen were reported

(Olson et al., 1956; Olson and Dreier, 1956). Grunes et al. (1958a) in field experiments in North and South Dakota observed that nitrogen increased the relative absorption of banded fertilizer phosphorus by sugar beets and potatoes. Similar results for winter wheat were reported from field experiments by Leikam et al. (1983).

Greenhouse studies have shown the same trend in results. Grunes et al. (1958b), working with barley, found that nitrogen increased phosphorus absorption. Similar observations were made by Miller and Ohlrogge (1958) for corn, Bouldin and Sample (1958) for oats and Werkhoven and Miller (1960) for sugar beets.

2.5.2 Distinction of the effect of nitrogen on phosphorus absorption

Various factors have been demonstrated to influence the extent to which nitrogen promotes absorption of fertilizer phosphorus. Many studies conducted on the effect of nitrogen on phosphorus absorption by plants, indicate that placement of nitrogen with respect to phosphorus is an important factor influencing the enhancement of phosphorus absorption. Apparently addition of nitrogen increases phosphorus absorption by plants only when nitrogen is placed in intimate association with phosphorus. Olson and Dreier (1956), working with oats in both field and greenhouse experiments, observed that nitrogen markedly influenced phosphorus absorption when it was applied with the banded phosphorus compared to when it was mixed with the soil. Miller and Ohlrogge (1958) from a greenhouse study with corn reported that nitrogen had a much greater effect on phosphorus absorption when nitrogen was placed in a common band with phosphorus than when the two

fertilizers were banded separately. Since nitrogen mixed with the phosphorus band increased the concentration of phosphorus in the plants uniformly at all levels of soil phosphorus, the authors explained that the increase in phosphorus absorption may be due to increased availability of the band phosphorus through chemical effects or an increase in relative root sorption surfaces in the band volume.

Rennie and Soper (1958) in greenhouse trials, observed substantial increase in fertilizer phosphorus absorption by wheat when NH_4NO_3 was added to the fertilizer phosphorus band. The authors however, observed no increase in phosphorus absorption when NH_4NO_3 was either mixed throughout the soil or banded 2.5 cm away from the phosphorus band. The effect of nitrogen on phosphorus absorption by sugar beets was found to be greater when nitrogen was banded together with phosphorus than when the two fertilizers were banded separately (Grunes et al., 1958b) or when phosphorus was banded and nitrogen mixed with the soil (Workhoven and Miller, 1960).

Leonce and Miller (1966) using corn as a test crop, placed a fertilizer phosphorus pellet 1.25 cm to the side and 5.0 cm above the tip of a root growing down the sloping front of a growth box. They found that inclusion of $(\text{NH}_4)_2\text{SO}_4$ with the phosphorus increased the concentration of phosphorus three-fold. However, placement of an $(\text{NH}_4)_2\text{SO}_4$ pellet 5.0 cm below the phosphorus pellet and 1.25 cm to the side of the same root did not affect plant phosphorus concentration. The authors concluded that the NH_4^+ ion must enter the root at the same point as phosphorus to cause increased P absorption.

From growth bench trials, Flaten and Racz (1982), working with spring wheat, reported that despite the fact that high concentrations of ammonia inhibited root growth in the nitrogen-phosphorus dual bands, fertilizer P uptake was stimulated once the roots penetrated into the bands. The authors also reported that phosphorus uptake was enhanced more when urea was placed in a common band with phosphorus than when the two materials were applied in separate bands, and fertilizer P uptake from separate bands declined with increasing distance from the seed row.

The volume of soil fertilized and the concentration of nitrogen and phosphorus have been investigated as factors affecting the extent to which nitrogen promotes fertilizer phosphorus absorption. Duncan and Ohlrogge (1958) reported that the volume in which the fertilizer was placed had an influence on the effect of nitrogen on phosphorus uptake. They found that when phosphorus was mixed throughout the soil, nitrogen had no effect on fertilizer phosphorus absorption but as the volume of the soil in which the fertilizer phosphorus in the presence of nitrogen was mixed decreased, the effect of nitrogen increased. The authors attributed these results to enhanced root development in the fertilized soil where nitrogen was included.

The addition of $(\text{NH}_4)_2\text{SO}_4$ increased the percentage of the plant phosphorus that sugar beets derived from fertilizer when the fertilizer phosphorus was banded but not when it was mixed throughout the soil (Grunes et al., 1958b). Werkhoven and Miller (1960) found that nitrogen affected sugar beet absorption of fertilizer phosphorus more when the phosphorus was applied in a band than when it was mixed with a 5-cm layer of soil. It appears that relatively high levels of nitrogen and

phosphorus are required for increased phosphorus absorption to occur. This is evidenced by the work of Mamaril and Miller (1970) in their series of investigations using corn as a test crop.

The source of nitrogen has also been found by various workers to influence the extent to which nitrogen promotes fertilizer phosphorus absorption. Lorenz and Johnson (1953) reported that yields of potatoes on nine different soils were considerably greater when $(\text{NH}_4)_2\text{SO}_4$ was used instead of $\text{Ca}(\text{NO}_3)_2$. In their investigation, NaNO_3 produced yields similar to those produced by $\text{Ca}(\text{NO}_3)_2$, whereas the yields produced by NH_4NO_3 were intermediate. The authors attributed this effect to an increased availability of soil and fertilizer phosphorus due to the acidifying effect of $(\text{NH}_4)_2\text{SO}_4$ and NH_4NO_3 . However, this theory was found by Rennie and Soper (1958) from greenhouse and field experiments, to be unsatisfactory; they found that addition of acid salt, KHSO_4 , to phosphorus carriers did not increase phosphorus uptake, but rather significantly reduced it. Their conclusion was that increased phosphorus uptake when NH_4^+ -fertilizers are applied was due to the ammonium ion effect, which occurs at an early stage of plant growth, not at a later stage which would be expected if the acidity effect is important.

Olson and Dreier (1956) reported a similar finding in their experiment with oats when they observed that the NH_4^+ and NH_4 -producing materials created maximum effect of nitrogen in promoting phosphorus uptake. Only ammonium salts had an influence on phosphorus absorption by wheat in studies by Rennie and Soper (1958) and neither KNO_3 nor K_2SO_4 was observed to have any effect.

In studies conducted by Leonce and Miller (1966) using corn as a test crop, they also found that $(\text{NH}_4)_2\text{SO}_4$ or NH_4Cl increased fertilizer phosphorus absorption whereas the addition of KNO_3 decreased it. They concluded that the NH_4^+ ion had a specific effect on the absorption of phosphorus by plants. Thus it appears that the NH_4^+ ion is the form of nitrogen that has the greatest effect on fertilizer phosphorus absorption. This has been shown to occur during early stages of plant growth.

2.5.3 Factors affecting ammonium-ion effect

It is apparent that $\text{NH}_4\text{-N}$ and NH_4 -producing fertilizers are responsible for increased phosphorus absorption (Lorenz and Johnson, 1953; Olson and Dreier, 1956; Rennie and Soper, 1958; Leonce and Miller, 1966). From this finding, it is inevitable that the factors which influence the transformation of NH_4^+ cation to NO_3^- anion under field conditions would affect the extent to which nitrogen promotes fertilizer P uptake.

Under typical soil conditions in which microbial development is limited by available carbon and energy, most of the ammonium is oxidized to nitrate (process called nitrification) very rapidly. Nitrification takes place in virtually all soils where ammonium is present and conditions are favorable with respect to ammonium concentration, aeration, soil pH, soil moisture and temperature. Chapman and Liebig (1952) found that addition of urea and anhydrous ammonia to calcareous soils caused nitrite accumulation.

When fertilizers are broadcast or mixed with soil under field conditions, NH_4^+ ion is often rapidly converted to nitrate, and, therefore because nitrate would be the main form of nitrogen absorbed, the pH at the soil-root interface may increase above that of the bulk soil when either ammonium or nitrate fertilizer is used (Nye, 1968) and this would be expected to lower phosphorus uptake in the soil where increasing pH decreases phosphorus availability. However, when fertilizers are banded, the NH_4^+ ion may remain in the soil as NH_4^+ for an appreciable period of time, and therefore, the plants absorb ammonium-N, particularly during the early stages of growth (Rennie and Soper, 1958), and the pH in the soil at the soil-root interface will decrease. Since soil pH influences phosphorus solubility, Riley and Barber (1969) hypothesized that if the form of nitrogen absorbed changes the pH of the rhizosphere soil, it will also alter the availability of phosphorus. Riley and Barber (1971), reported similar results when they found that ammonium-fertilized soybeans absorbed more phosphorus and had higher phosphorus concentration than nitrate-fertilized soybeans. This seems to explain why the banded ammonium fertilizer must be placed at the same location as banded phosphorus (Leonce and Miller, 1966).

2.5.4 Possible mechanisms responsible for the effect of nitrogen on phosphorus uptake by plants

Placement of nitrogen and phosphorus in a common band has been shown to increase fertilizer phosphorus content of plant shoots. Several studies have indicated that the addition of nitrogen in a fertilizer phosphorus band causes a proliferation of roots in the band volume

(Miller and Ohlrogge, 1958). Duncan and Ohlrogge (1958, 1959) in their investigation found that a combination of nitrogen and phosphorus greatly increased root development. Further studies by Duncan and Ohlrogge (1959) and Miller and Vij (1962) have indicated that inclusion of $(\text{NH}_4)_2\text{SO}_4$ in a fertilizer P band resulted in a dense mass of roots that grew in and around the volume of the fertilized soil. Although increased root growth is not sufficient to explain all the observed effects of nitrogen on phosphorus absorption, it is apparent that the combination of nitrogen and phosphorus in a fertilizer band has a stimulating effect on roots in the band, resulting in an increase in phosphorus absorption from the band.

Various workers (Bouldin and Sample, 1958; Miller and Vij, 1962; Blanchar and Caldwell, 1966) have shown that the effect of nitrogen on fertilizer phosphorus absorption is not due to an increased movement of fertilizer phosphorus from the band.

It is well known that fertilizer phosphorus in solution at the root surface is a function of the solubility of fertilizer phosphorus reaction products and the movement to the root surface. From research work conducted (Starostka and Hill, 1954; Rennie and Mitchell, 1954; Bouldin and Sample, 1958, 1959; Blanchar and Caldwell, 1966), it can be concluded that although there are chemical effects of salts in a fertilizer band, the influence of nitrogen salts on the solubility of the fertilizer phosphorus has not been shown to be a major factor responsible for the increased absorption of fertilizer phosphorus.

Phosphorus is regarded as being relatively immobile in the soil and is considered to move to the plant root primarily by diffusion (Barber, 1962). However, in a concentrated fertilizer band, it is feasible that the concentration in solution would be sufficient to allow a significant amount of fertilizer phosphorus to move to the root surface by mass-flow. The evidence provided by various workers on the movement of fertilizer phosphorus to the root surface (Minshall, 1964; Olsen and Kemper, 1968) is not enough to suggest that the increased fertilizer phosphorus absorption in the presence of nitrogen is due to a greater rate of movement of fertilizer phosphorus to the root surface.

Electroneutrality must be maintained across the membrane during absorption. Therefore, either (1) the same number of anions and cations must be absorbed, (2) there must be an exchange of similarly charged ions in the root for those ions absorbed, or (3) there must be a shift of the organic acid balance within the cell to maintain neutrality. Research work that has been conducted (Arnon, 1939; Blair et al., 1970; Riley and Barber, 1971) indicates that there is a clear evidence that the source of nitrogen, ammonium or nitrate, affects the ability of the plant to absorb phosphorus. This could explain the increased absorption when ammonium salts are applied with fertilizer P in a common band.

Cole et al. (1963) found that pretreatment of the plants with N caused a pronounced increase in P absorption per unit weight of roots and also stimulated translocation of P to the plant tops, the effects of which suggested to the authors that there was a connection between P uptake and N metabolism. They hypothesized that the increase in P uptake rates may reflect higher levels of N intermediates whose syntheses have

processes in common with those of P uptake. This effect, they felt, might explain the higher proportion of fertilizer P to soil P taken up by plants when N is added. Thien and McFee (1970) confirmed the results of Cole et al. (1963) and concluded that there was no companion ion effect of nitrogen on P absorption as suggested by Arnon (1939). The influence of pretreatment nitrogen on labelled phosphorus content of the shoots was greater than on that of the roots, indicating a different effect of nitrogen on translocation than on absorption. This suggested to the authors the existence of an intermediate acting in two transport systems, across the initial cellular barrier and in the system responsible for moving P to the Xylem.

Miller et al. (1970) with electron microprobe scans of root cross sections, showed that the fertilizer P was precipitated on the root surface in association with Ca^{+2} ions in the absence of ammonium ions, but no such precipitation was observed when ammonium ion was present in the fertilizer pellet. This indicated that the NH_4^+ ion caused a reaction at the soil-root interface which prevented the precipitation of fertilizer P and increased its absorption.

Research work by Miller et al. (1970) indicated that the ammonium ion causes a lowering in pH at the soil-root interface, which reduces the tendency for precipitation of $\text{CaHPO}_4 \cdot 2\text{H}_2\text{O}$ at a given P concentration. The reduction in pH at the soil-root interface in the presence of ammonium ions was hypothesized (Miller et al., 1970) to be due to exchange of H^+ ions from within the root for NH_4^+ or K^+ ion in the soil solution.

Riley and Barber (1969), reported that when nitrogen was absorbed as NH_4^+ ions, cation uptake exceeded anion uptake and H^+ were released to balance the charge, lowering the root pH. Conversely, when nitrogen was absorbed as NO_3^- ions, anion uptake was enhanced and OH^- ions or HCO_3^- ions were released to balance the excess anion absorption, increasing the root pH. Riley and Barber (1971), reported that fertilization of soybeans with ammonium N decreased the pH of the rhizocylinder (root plus strongly adhering soil) and fertilization with nitrate N increased the rhizocylinder pH. Decrease in the pH of the soil-root interface brought about by the unequal uptake of cations and anions and the resulting increase of H_2PO_4^- anions was concluded to be responsible for the increased P uptake during the very early growth period when ammonium accompanied phosphorus.

The higher the proportion of P in the form of H_2PO_4^- anions at the lower pH would also increase the absorption by the root because of the greater rate of absorption of H_2PO_4^- anions compared to HPO_4^{2-} anions (Hagen and Hopkins, 1955).

2.6 EFFECT OF PHOSPHORUS PLACEMENT ON YIELD AND PHOSPHORUS CONTENT OF PLANTS

Over recent years considerable research interest have been directed towards placement of phosphorus fertilizers. The strategy of phosphorus placement is basically to place the fertilizer in a position where it can be accessible to plant roots during the early stage of plant growth. Phosphorus has unique characteristics of interacting with soil

components and forming compounds of relatively low solubility which remain localized at the point of application. The importance of precise placement of phosphorus in a position where it can be utilized by plants during early stages of plant growth has been demonstrated (Strong and Soper, 1974a, 1974b). Terman et al. (1961) reported that nutrient requirement and uptake was greatest in young plants and decreases as plants mature. Similar observations were reported by Warncke and Barber (1974) in culture solution experiments on corn. Solution culture studies by Boatwright and Viets (1966) showed that early utilization of phosphorus by wheat resulted in increased yields and promoted tillering and secondary root development.

Response of plants to banded or broadcast fertilizer phosphorus has been associated with the amount of free carbonates in the surface soil. Thus, Barber (1958) working with wheat in soils that had no free carbonates in the surface, reported that band and broadcast applications of phosphorus resulted in similar yields on soils that had adequate levels of available phosphorus. However, on soils that contained free carbonates in the surface horizons, banding of phosphorus was found to be superior to broadcasting for wheat (Olsen and Dreier, 1956; Meelu et al., 1974; Hamid and Sarwar, 1977).

Band placement of phosphorus fertilizers away from the seed has been shown to be a useful alternative because it allows use of higher rates to improve crop yields. Sherrell et al. (1964), reported that for oats grown on soils low in available phosphorus, banding phosphorus below the seed resulted in higher yields than banding with or to the side of the seed. Placement of phosphorus away from the seed also allows banding

nitrogen and phosphorus together. One of the more recent developments in nitrogen and phosphorus placement technology is pre-plant deep banding. Several researchers have reported advantages associated with this technique in terms of crop yields and phosphorus content. Leikam et al. (1977) in preliminary studies in Kansas on winter wheat reported results which indicated that pre-plant, simultaneous "knife" applications of anhydrous ammonia (NH_3) or urea ammonium nitrate (UAN) solution with liquid ammonium polyphosphate (APP) increased leaf tissue phosphorus concentration and grain yield. The authors compared pre-plant applications of nitrogen and phosphorus in a single band (termed "dual knife") with conventional pre-plant nitrogen and phosphorus applications (broadcast or with seed) which separate the two fertilizers and were convinced of the superiority of "dual knife" applications. The same authors found similar results in the subsequent two years, when they reported that anhydrous NH_3 -APP or UAN-APP (banded 13 cm below the surface in bands 46 cm apart) combinations significantly increased leaf tissue phosphorus concentration and yield compared to surface applied or UAN and APP.

Yield responses to band applied phosphorus has been suggested (Olson and Sander, 1977) to be twice that obtained from broadcast phosphorus on soils with low levels of phosphorus. But as the level of soil phosphorus increases the difference between the two placement methods diminishes (Peterson et al., 1981). Banding phosphorus away from the seed has been shown to have no significance for cereal crops (Bailey, 1979) when low rates are applied. However, Bailey et al. (1980) reported increased yields at higher rates of phosphorus application, particularly for small

seeded crops like canola or flax when phosphorus was banded below or below and to the side of the seed compared to equal rates of phosphorus placed with the seed. The deleterious effects of phosphorus placed with the seed is mainly associated with seed injury (Nyborg and Hennig, 1969). The authors reported higher yields of rapeseed at higher rates of applied phosphorus when the fertilizer was banded away from the seed than when it was placed with the seed.

2.7 FACTORS AFFECTING THE QUALITY OF OIL SEEDS

It is well known that nutritional effects on crop quality are dependent on the influence of particular nutrients on biochemical or physiological processes. Carbohydrate, sugar, and oil contents in storage tissues, grains and seeds are related to the photosynthetic activity of the plant and to the translocation rate of photosynthates to the storage plant parts (Mengel and Kirkby, 1978). In oil crops like any other seed-bearing crops, there is tremendous competition for photosynthates between different metabolic sinks. Schmalfluss (1963), using low and high levels of nitrogen in an experiment with flax (Linum usitatissimum L.), found that at high levels of nitrogen there was an enhancement of crude protein content from about 22 to 28 % but a decrease in the oil content. Similar findings of this inverse relationship between protein and oil content were reported by Appelquist (1968) for rape (Brassica napus L.). The author contended that the beneficial effect of lower level nitrogen nutrition in terms of oil content may be related to earlier senescence of leaves, which reduced the rate of seed filling during maturation. Ridley (1972), working with

rapeseed, reported results similar to those of Appelquist (1968) when he observed an inverse relationship between protein and oil content with increasing rates of nitrogen applied.

High rates of nitrogen were found to have a negative effect on rape quality. Hermann (1977) reported increase in erucic acid in rape oil with increasing rates of nitrogen.

The quality of oil seeds has also been found to be affected by climate. Oil seeds grown at low temperatures are comparatively richer in unsaturated fatty acids than saturated fatty acids (Ivanov, 1929; Barker and Hilditch, 1950; Beringer, 1971). This results were confirmed by Beringer and Saxena (1968) in experiments with sunflowers, flax and oats. The higher contents of unsaturated fatty acids found in oil seeds from plants grown under low temperatures can be explained by the greater O_2 pressure in the seeds. This favours the desaturation of saturated to unsaturated fatty acids, since oxygen is required for this oxidation (Harris and James, 1969; Dompert and Beringer, 1970).

Chapter III

GENERAL MATERIALS AND METHODS

3.1 SOIL ANALYSIS

3.1.1 Soil pH and Conductivity

Soil pH was measured in water electrometrically by the methods described by Peech (1965). A 1:1 ratio of soil:water was used. To 20 g of air-dry soil in a 50-ml beaker, 20 ml of distilled water was added, and the solution stirred. The solution was allowed to sit for 30 minutes, mixing once during that period and the pH determined using a Beckman Zeromatic pH meter. Conductivity was determined on the same suspension using the conductivity meter.

3.1.2 NaHCO₃-Extractable P

Phosphorus extraction was done according to the procedure described by Olsen et al. (1954). Five grams of air-dry soil were extracted with 100 ml of 0.5 M NaHCO₃ solution initially adjusted to a pH of 8.5. Color development was done by the modified method described by Murphy and Riley (1962) using a single solution reagent. To 10 ml of the extract 2 ml of an acidic molybdate solution containing ascorbic acid was added, which formed and reduced phosphomolybdic acid to phosphomolybdenum blue, the intensity of which is proportional to phosphorus concentration in the extract. The absorbance was read on the spectrophotometer

(Spectronic 710) at 885 nm. Appropriate calculations based on the standard curve and the dilution factor gave the NaHCO_3 -extractable phosphorus in ppm.

3.1.3 Nitrate-Nitrogen

Nitrate-nitrogen was determined using the modified method described by Harper (1924). Ten grams of soil were extracted with 50 ml of the extracting solution (mixture of 20 ml of 0.5 M $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ and 100 ml of 0.02 M Ag_2SO_4 in one litre). Nitrogen was determined colorimetrically using a spectrophotometer (Spectronic 710) at 415 nm; in this method nitrogen was in the nitro form of phenoldisulphonic acid (6-nitrophenol-2,4-disulphonic acid) which is yellow in alkaline solution.

3.1.4 Exchangeable Potassium

Exchangeable potassium was determined according to the modified procedure described by Pratt (1965). Five grams of soil were extracted with 100 ml 1 N ammonium acetate (pH 7.0) by shaking for one hour. Filtration was done using #1 filter paper. One millilitre of the extract was pipetted into a 15-ml centrifuge tube. Then 1 ml of 2500 ppm LiNO_3 solution was added and the final volume made to 10 ml using deionized water. Potassium concentration (ppm) was determined on the Atomic Absorption (Perkin Elmer 560).

3.1.5 Sulfate-Sulfur

Sulfate-Sulfur was determined by the modified method described by Lazrus (1965). Twenty five grams of soil were weighed into shaking flasks. Fifty ml of CaCl_2 (1×10^{-2} M) solution were added and the contents shaken for 30 minutes. The suspension was then filtered through #42 filter paper and analyzed for $\text{SO}_4\text{-S}$ on the Auto Analyzer II System. In the Auto Analyzer II, the extract was passed through a cation exchange resin and reacted with a solution containing 1.526 g l^{-1} BaCl_2 and 0.236 g l^{-1} methylthymol blue at a pH of 2.5-3.0. Excess BaCl_2 reacted with methylthymol blue to form a blue colored chelate at a pH of 12.5 to 13.0. The amount of uncomplexed methylthymol blue (gray color) measured at 460 nm on the Auto Analyzer II was a measure of $\text{SO}_4^{2-}\text{-S}$ concentration in the extract.

3.1.6 Organic Matter

Organic matter was determined by the Walkley-Black (1934) procedure as described by Allison (1965). To 0.5 g of the soil in a 400-ml beaker, 10 ml of $\text{K}_2\text{Cr}_2\text{O}_7$ was added. Then while swirling the beaker, 20 ml of concentrated H_2SO_4 was added and allowed to sit for a minimum of 30 minutes. Distilled water was added to bring the volume to 250 ml mark. Excess $\text{K}_2\text{Cr}_2\text{O}_7$ was back-titrated with 0.5 M $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ using an Auto-titrator.

3.2 PLANT ANALYSIS

3.2.1 Total Nitrogen

Total nitrogen was determined by a modified Kjeldal Procedure (Jackson, 1958).

3.2.2 Total Phosphorus

One gram of a representative sample of plant material was digested with concentrated $\text{HNO}_3\text{-HClO}_4$ mixture according to the modified procedure outlined by Jackson (1958). The digest was diluted to 100 mls and thoroughly shaken. After the sediment had settled, 1 ml of sample was drawn and diluted to 10 ml. A final dilution was made by taking 1 ml from the 10 ml and diluting to 10 ml. Color development was attained by the procedure described by Murphy and Riley (1962) using a single solution reagent. Two ml of the solution was added to the diluted digest. The intensity of the blue color was a measure of P concentration in the sample and was read on the Spectrophotometer (Spectronic 710) at 885 nm.

3.2.3 Phosphorus derived from fertilizer

In the experiments which involved the use of ^{32}P , 2 g of ground plant material were digested as described in the preceding section. The digest was then diluted to 25 ml. This was used for the determination of both total phosphorus and fertilizer phosphorus. Total phosphorus was determined as described before. For the determination of fertilizer phosphorus, 15 ml of the diluted digest were placed in the plastic vials and the activity (counts min.^{-1}) measured on the Scintillation Counter (Beckman model 7500).

After the correction for the dilution had been made on the counts min.^{-1} , the specific activity of the samples and the standard was determined by the expression,

$$\text{Specific activity} = \frac{\text{Counts Min}^{-1}}{\text{Total P (mg)}}$$

Phosphorus derived from fertilizer (% Pdf) was then calculated from the equation,

$$\% \text{ Pdf} = \frac{\text{(Specific activity of sample)}}{\text{(Specific activity of standard)}} \times 100$$

and the Phosphorus derived from the soil (% Pdfs) was then calculated from,

$$\% \text{ Pdfs} = (100 - \% \text{ Pdf}).$$

3.2.4 Statistical Analysis

Statistical analysis of the data in all experiments was done using analysis of variance. The F value was used to compare the treatments. Tukey's "w" procedure ($P=0.05$) was used to determine the differences among the treatments.

Chapter IV

FIELD EXPERIMENT 1

4.1 EFFECT OF N AND P PLACEMENT ON YIELDS, P UPTAKE AND QUALITY OF CANOLA AND FLAX

4.1.1 Introduction

Placement of nitrogen and phosphorus for oilseed crops has been limited until recently to broadcast nitrogen with low rates of phosphorus applied with the seed or to both fertilizers broadcast for non-row crops. Low rates of phosphorus placed with the seed were essential to reduce seedling injury and this placed limitations on the ability to economically produce maximum yields. The relative inefficiency of broadcast fertilizers similarly limited the achievement of maximum yields.

For over three decades now documentation on the effect of nitrogen on phosphorus absorption by plants and yield increase has illustrated the importance of placing nitrogen and phosphorus in a common band. Banding fertilizers, especially at greater depths away from the seed has allowed use of higher rates of fertilizers to produce maximum yields without causing seedling injury.

The objectives of this study were to (1) determine the effectiveness of various N-P placement methods on yield and phosphorus accumulation of canola and flax, and (2) evaluate the effects of these treatments on crop quality (protein and oil content).

4.1.2 Materials and Methods

In the fall of 1983 an N-P placement study was initiated on Holland VFSL at Treherne (NW4-8-10W) using canola and flax as test crops. The sites were selected because of medium soil phosphorus concentration (Table 1).

The experiment consisted of a randomized complete block design with 12 treatments and five replications for each crop. Plots were 1.5 m wide by 6.0 m long, and each plot consisted of 8 rows of crop at 18 cm spacing. The design, treatments and replications were identical for both canola and flax. The plot areas for canola and flax were located adjacent to each other.

Before fall treatments were administered, soil samples were taken on the plot area for fertility characterization (Table 1). All the nitrogen that was fall applied was placed in deep bands 15 cm below the soil surface at the rates of 90 and 180 kg N ha⁻¹ as urea (46-0-0) using a 4-row fertilizer bander equipped with chisel points, with shanks set 36 cm apart. Fall applied phosphorus, monoammonium phosphate (11-51-0), was either deep banded with the nitrogen at the rates of 20 and 30 kg P ha⁻¹ or broadcast and incorporated to a depth of 7.5 cm at the rates of 30 and 60 kg P ha⁻¹.

At planting time, soil sampling was done for fertility characterization (Table 1). Nitrogen applied in spring was broadcast and incorporated at the rate of 90 kg N ha⁻¹. Phosphorus was either drilled in with the seed at the rate of 10 kg P ha⁻¹ or placed 2.5 cm directly below the seed row at the rates of 10 and 30 kg P ha⁻¹ using the 8-row fertilizer-seed drill with V-belt combination.

The combination of N-P placement techniques is shown in the tables of the results. On the plot area for canola, Treflan EC was applied pre-plant and incorporated at the maximum recommended rate of 2.6 L ha⁻¹ to control grass weeds (green and yellow foxtail) and several broadleaf weeds. Hoe-Grass was applied (postemergence) at the recommended rate of 1.60 L ha⁻¹ to control wild oats, green and yellow foxtail, barnyard grass and several broadleaf weeds in flax.

Canola (Brassica napus L., var. Regent) and flax (Linum usitatissimum, var. Dufferin) were seeded on May 29 at Treherne to a depth of 2.5 cm at the rates of 8 and 40 kg ha⁻¹, respectively.

Plant sampling was done on the above ground portions at flowering time (full flower) for dry matter yield and P uptake determination. The area sampled was 0.3 m x 0.72 m (4 centre rows). The small area was chosen in order to leave adequate area for final harvest. The samples were oven-dried at 60 °C and weighed to determine dry matter yield. Oven-dry samples were then ground in a Wiley mill for P analysis.

Similarly at maturity the harvested materials were air-dried, threshed, and yield components determined. The area harvested was 1 m x 0.72 m (4 centre rows) for canola and 2 m x 0.72 m (4 centre rows) for

flax. Straw samples were ground in a Wiley mill for P analysis. The digestion of grain samples for N and P analyses was done on intact grain. Protein content was obtained by multiplying % N of the seed by a factor of 6.25.

Oil content was determined by Nuclear Magnetic Resonance Spectrometry procedure as outlined by Madsen (1976) using Newport Quantity Analyzer MK II. Twenty grams of seed were weighed into Nessler tubes. The samples were oven-dried at 105 °C for a period of 16 hours prior to analysis. The samples were then weighed again to 3 decimal places on the Mettler PC 440 Delta Range. A mean of 3 counts was recorded for each sample. Four counts of the standard were recorded after every 10 samples. Percent oil content in the sample was then calculated from

$$\% \text{ Oil} = \frac{(\% \text{ oil in standard}) \times (\text{standard weight}) \times (\text{mean sample count})}{(\text{sample weight}) \times (\text{mean standard count})}$$

The standard sample used for canola had 46.5 % oil and weighed 25.001 g and flax had 42.6 % oil with a weight of 25.002 g.

TABLE 1
 Characteristics of the soil used for field experiment 1

Time	Fall	Spring
Location	Treherne	Treherne
Soil series	Holland CL	Holland CL
Soil type	Black chernozem ¹	Black chernozem ¹
Carbonate content	Very low	Very low
pH	7.2	6.5
NO ₃ -N (kg ha ⁻¹) (0-60 cm)	35.0	47.0
NaHCO ₃ -P (ppm) (0-15 cm)	8.4	9.0
Exchangeable K (ppm) (0-15 cm)	288.0	352.0
SO ₄ -S (kg ha ⁻¹) (0-60 cm)	67.0	44.0

¹Black chernozem developed on lacustrine and delta deposits (Soil classification by Ellis and Shafer (1943))

4.1.3 Results and discussion

At Treherne, soils were very dry when fertilizer was applied in the fall of 1983. Dry conditions prevailed in the spring of 1984 making seed and fertilizer placement difficult. High winds at the time of crop emergence seriously abraded the seedlings leading to poor crop. Dry weather conditions were prevalent, particularly starting from the time when the plants were flowering to maturity. This serious moisture limitation may have affected the results observed.

4.1.3.1 The effect of N-P placement on dry matter yield, tissue P concentration and P accumulation of canola at flowering stage at Treherne

Yields of canola at flowering were variable between replicates. This resulted in a high standard error and few differences in yields were detected by statistical analysis (Table 2). Undoubtedly the serious moisture limitation during the growing season was a major factor that contributed to the variability in results.

Lowest yields at flowering were obtained where no N was applied, indicating that the plot site was deficient in nitrogen. Response to P was less evident, and only where P was applied with the seed (N fall banded at 90 kg N ha^{-1}); or where P was fall broadcast at 60 kg P ha^{-1} was there a significant response to P.

Tissue P concentrations at flowering stage were not significantly affected by P fertilization or method of placement (Table 2). Where nitrogen (90 kg N ha^{-1}) was broadcast in spring, tissue P concentrations

ranged from 0.27 % in the phosphorus control plot to 0.32 % in the plot where P (30 kg P ha⁻¹) was placed below the seed. This range in concentration (0.05 %) was statistically non-significant.

Where nitrogen at 90 kg N ha⁻¹ was deep banded in fall, P concentrations ranged from 0.31 % in the plot where 30 kg P ha⁻¹ were placed below the seed to 0.39 % in the plot where 30 kg P ha⁻¹ were fall banded with nitrogen. Although this range in concentration (0.08 %) was high, no statistical differences were observed and this was attributed to the high variability in tissue P concentrations among replicates.

Where nitrogen at 180 kg N ha⁻¹ was deep banded in fall, tissue P concentrations ranged from 0.23 % in the plot where P was deep banded in combination with N to 0.33 % in the plot where the highest rate of P (60 kg P ha⁻¹) was broadcast in fall. This range in concentration (0.10 %) was however non-significant. There was no significant difference in terms of tissue P concentration between the treatment where 30 kg P ha⁻¹ were fall broadcast as compared to that where 60 kg P ha⁻¹ were fall broadcast, indicating no P rate effect at the high nitrogen level.

A comparison of P concentrations of the plants in the plots where P (30 kg P ha⁻¹) was deep banded in fall in combination with 90 or 180 kg N ha⁻¹ indicated no significant effect of extra nitrogen. The lowest concentration of P in canola tissue at flowering (0.23 %) was observed where a high rate of nitrogen (180 kg N ha⁻¹) was applied in a band along with P at 30 kg P ha⁻¹. This contrasts to a tissue concentration of 0.39 % where only 90 kg N ha⁻¹ was applied along with the P. The reduction in P concentration when a high rate of nitrogen (180 kg N ha⁻¹) was applied was however, not statistically significant.

Total P accumulation is a function of total yield and total plant P concentration and the trends observed in yield and tissue P concentration are generally reflected in total P accumulation. Yields and P concentrations were highly variable and so was total P accumulation (Table 2). Lowest P uptake occurred on treatments where no nitrogen was applied and this was consistent with the lowest yield. Highest P uptake occurred with 90 kg N ha⁻¹ and 30 kg P ha⁻¹ fall banded; fall banded nitrogen (90 kg ha⁻¹) and 10 kg P ha⁻¹ placed with the seed; and 180 kg N ha⁻¹ fall banded and 60 kg P ha⁻¹ fall broadcast. This trend in uptake is not a clear one since the three treatments that resulted in the highest P uptake had confounding effects of rates of N and P, and placement methods.

TABLE 2

The effect of N-P placement on dry matter yield, tissue P concentration and P uptake of canola at flowering stage

Rates and Placement Methods		Yield (kg ha ⁻¹)	P concentration (% P)	P uptake (kg ha ⁻¹)
Nitrogen	Phosphorus			
Spring broadcast (90)	- (0)	4712 cde	0.27 a	12.7 ab
Spring broadcast (90)	With Seed (10)	5479 abcd	0.29 a	15.7 ab
Spring broadcast (90)	Below Seed (10)	5144 bcd	0.29 a	15.1 ab
Spring broadcast (90)	Below Seed (30)	4984 bcd	0.32 a	15.7 ab
- (0)	Fall banded (20) ¹	3290 e	0.31 a	10.3 b
Fall banded (90)	Fall banded (20) ¹	4271 de	0.34 a	14.5 ab
Fall banded (90)	Fall banded (30)	5863 abc	0.39 a	22.3 a
Fall banded (90)	With Seed (10)	6482 ab	0.34 a	21.8 a
Fall banded (90)	Below Seed (30)	5131 bcd	0.31 a	16.1 ab
Fall banded (180)	Fall banded (30)	5739 abcd	0.23 a	13.2 ab
Fall banded (180)	Fall broadcast (30)	5641 abcd	0.29 a	16.2 ab
Fall banded (180)	Fall broadcast (60)	6705 a	0.33 a	21.9 a

All the figures in parentheses are rates of the respective elements in kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

¹Additional 10 kg ha⁻¹ was placed with seed

All bands were placed 15 cm below the surface

4.1.3.2 The effect of N-P placement on canola at maturity

Yield of canola at maturity ranged from 1289 to 2048 kg seed ha⁻¹ which is generally low considering the rates of nutrient input (Table 3). There was no significant response to nitrogen at 90 kg N ha⁻¹ either spring broadcast or fall banded. Similarly no significant response was obtained at 180 kg N ha⁻¹. In general, phosphorus increased seed yield of canola but not significantly compared to the phosphorus control. Phosphorus fall broadcast at 60 kg P ha⁻¹ resulted in seed yields that were amongst the highest obtained but no other yield trends resulting from method of placement were obvious.

Phosphorus concentration in the seed ranged from 0.25 to 0.61 % (Table 3). Highest P concentration occurred in the treatment in which no nitrogen was applied and this was significantly greater than the phosphorus control, and the treatments where 90 kg N ha⁻¹ were either fall banded or spring broadcast and P (10 kg P ha⁻¹) was placed with the seed. Phosphorus concentration was generally low in treatments in which P was applied with the seed but this may be due to a dilution effect because these treatments tended to be high in yield.

Total P accumulation was not considerably affected by either rate of application or method of P placement when nitrogen was spring broadcast or deep banded in fall at the rates of 90 and 180 kg N ha⁻¹ (Table 3). The highest amount of P taken up was observed in the plants from the plot where the highest rates of nitrogen and phosphorus were banded and broadcast, respectively, in fall.

TABLE 3

The effect of N-P placement on yield, P concentration and total P of the seed of canola

Rates and Placement Methods		Yield (kg ha ⁻¹)	P concentration (% P)	Total P (kg ha ⁻¹)
Nitrogen	Phosphorus			
Spring broadcast (90)	- (0)	1301 c	0.25 c	3.3 d
Spring broadcast (90)	With Seed (10)	1894 abc	0.32 bc	6.2 bcd
Spring broadcast (90)	Below Seed (10)	1790 abc	0.41 abc	7.4 abcd
Spring broadcast (90)	Below Seed (30)	1509 abc	0.45 abc	6.8 abcd
- (0)	Fall banded (20) ¹	1645 abc	0.61 a	10.0 abc
Fall banded (90)	Fall banded (20) ¹	1289 c	0.38 abc	4.9 cd
Fall banded (90)	Fall banded (30)	1800 abc	0.46 abc	8.3 abcd
Fall banded (90)	With Seed (10)	1842 abc	0.36 bc	6.5 abcd
Fall banded (90)	Below Seed (30)	1336 bc	0.46 abc	6.1 bcd
Fall banded (180)	Fall banded (30)	1973 a	0.50 ab	10.2 ab
Fall banded (180)	Fall broadcast (30)	1931 ab	0.53 ab	10.2 ab
Fall banded (180)	Fall broadcast (60)	2048 a	0.56 ab	11.4 a

All the figures in parentheses are rates of the respective elements in kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

¹ Additional 10 kg ha⁻¹ was placed with seed

Straw yields were 2 to 3 times greater than seed yield. Straw yield however, was not significantly affected by treatment (Table 4). The P concentration in the straw was also high, ranging from 0.19 to 0.28 percent, and is an indication that optimum P translocation did not occur (Table 4). Lack of optimum translocation may be associated with the serious moisture limitation that persisted during the growing season, since water acts as a medium of nutrient translocation within plants among other physical and chemical functions. More than half the amount of P that was measured in the above ground portion of the plants remained in straw (Table 4). This may have caused limitation on seed yield of canola.

Similar trends in results were reflected in total crop yield and P uptake (Table 5). In general, yields did not differ significantly between the treatments that were to be compared for effect of method of N-P application. Likewise total P accumulation did not differ significantly between treatments (Table 5).

Protein and oil content of canola seed was generally not affected by N-P treatments (Table 6). There appears however, to be an inverse relationship between the two components of crop quality as the sum of % protein and % oil is virtually constant for all treatments. These results are in accordance with the findings of Appelquist (1968) and Ridley (1972) on rape, who reported an inverse relationship between protein and oil content at low and high levels of nitrogen. The explanation to the inverse relationship between protein and oil content

may be associated to the fact that low nitrogen causes earlier senescence of leaves, which reduces the rate of seed filling during maturation. This results in depressed seed yield, seed size, and protein content but increased oil content due to concentration effect (Appelquist, 1968).

TABLE 4

The effect of N-P placement on yield, P concentration and total P of the straw of canola.

Rates and Placement Methods		Yield (kg ha ⁻¹)	P concentration (% P)	Total P (kg ha ⁻¹)
Nitrogen	Phosphorus			
Spring broadcast (90)	- (0)	4375 ab	0.25 a	11.0 a
Spring broadcast (90)	With Seed (10)	4331 ab	0.25 a	11.0 a
Spring broadcast (90)	Below Seed (10)	4340 ab	0.24 a	10.2 a
Spring broadcast (90)	Below Seed (30)	4082 ab	0.25 a	10.3 a
- (0)	Fall banded (20) ¹	3618 b	0.28 a	10.0 a
Fall banded (90)	Fall banded (20) ¹	3571 b	0.25 a	8.9 a
Fall banded (90)	Fall banded (30)	4200 ab	0.23 a	9.6 a
Fall banded (90)	With Seed (10)	4485 ab	0.19 a	8.6 a
Fall banded (90)	Below Seed (30)	3726 ab	0.24 a	8.7 a
Fall banded (180)	Fall banded (30)	4823 a	0.19 a	9.4 a
Fall banded (180)	Fall broadcast (30)	4242 ab	0.24 a	10.1 a
Fall banded (180)	Fall broadcast (60)	4120 ab	0.22 a	8.8 a

All the figures in parentheses are rates of the respective elements in kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

¹Additional 10 kg ha⁻¹ was placed with seed

TABLE 5

The effect of N-P placement on total crop yield and P uptake of canola at maturity

Rates and Placement Methods				Total crop yield (kg ha ⁻¹)	P uptake (kg ha ⁻¹)
Nitrogen		Phosphorus			
Spring broadcast	(90)	-	(0)	5676 ab	14.3 a
Spring broadcast	(90)	With Seed	(10)	6224 ab	17.2 a
Spring broadcast	(90)	Below Seed	(10)	6131 ab	17.6 a
Spring broadcast	(90)	Below Seed	(30)	5592 ab	17.1 a
-	(0)	Fall banded	(20) ¹	5263 ab	20.0 a
Fall banded	(90)	Fall banded	(20) ¹	4860 b	13.8 a
Fall banded	(90)	Fall banded	(30)	5999 ab	17.9 a
Fall banded	(90)	With Seed	(10)	6327 ab	15.1 a
Fall banded	(90)	Below Seed	(30)	5062 b	14.8 a
Fall banded	(180)	Fall banded	(30)	6796 a	19.6 a
Fall banded	(180)	Fall broadcast	(30)	6173 ab	20.3 a
Fall banded	(180)	Fall broadcast	(60)	6168 ab	20.2 a

All the figures in parentheses are rates of the respective elements in kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

¹Additional 10 kg ha⁻¹ was placed with seed

TABLE 6

The effect of N-P placement on protein and oil content of canola

Rates and Placement Methods				Protein content (%)	Oil content ¹ (%)
Nitrogen		Phosphorus			
Spring broadcast	(90)	-	(0)	28 ab	43 ab
Spring broadcast	(90)	With Seed	(10)	25 b	45 ab
Spring broadcast	(90)	Below Seed	(10)	25 b	45 ab
Spring broadcast	(90)	Below Seed	(30)	28 ab	42 b
-	(0)	Fall banded	(20) ²	24 b	46 a
Fall banded	(90)	Fall banded	(20) ²	30 a	42 b
Fall banded	(90)	Fall banded	(30)	26 ab	44 ab
Fall banded	(90)	With Seed	(10)	27 ab	44 ab
Fall banded	(90)	Below Seed	(30)	28 ab	42 b
Fall banded	(180)	Fall banded	(30)	27 ab	44 ab
Fall banded	(180)	Fall broadcast	(30)	26 ab	44 ab
Fall banded	(180)	Fall broadcast	(60)	27 ab	43 ab

¹Seed oil analysis, courtesy of Katherine Cseres, Plant Science DepartmentAll the figures in parentheses are rates of the respective elements in kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

²Additional 10 kg ha⁻¹ was placed with seed

4.1.3.3 The effect of N-P placement on dry matter yield, tissue P concentration and total P accumulation of flax at flowering stage

Dry matter production of flax at flowering stage was not markedly affected by treatments (Table 7). Whether nitrogen was spring broadcast (90 kg N ha^{-1}) or fall deep banded (90 or 180 kg N ha^{-1}) P placement methods or rate of application did not substantially influence yields. Highest yield, which was significantly different from that obtained from the plot where no P was added, was obtained from the treatment where the highest rates of N and P were added as fall band and broadcast applications, respectively.

Tissue P concentrations of flax ranged from 0.15 to 0.18 % in all the treatments and this range (0.03 %) was not statistically significant (Table 7). Tissue P concentrations were low at this stage of plant growth according to the rating of the Manitoba Provincial Soil Testing Laboratory². Lack of moisture may have reduced phosphorus uptake and thus low P concentration was a manifestation of drought.

Total P accumulation is a function of total yield and total plant P concentration and similar trends observed in yields and tissue P concentrations are exhibited in the data of total accumulated P (Table 7). Total accumulated P showed similar trends to those observed in dry matter production since the values in tissue P concentration did not

² Interpretive Guidelines for plant tissue analysis used by the Manitoba Provincial Soil Testing Laboratory, June 1982, Department of Soil Science, University of Manitoba, Winnipeg, Manitoba.

differ considerably among treatments. Generally the amount of P accumulated by flax were not significantly affected by treatments. The highest amount of P accumulated was observed in the treatment where the highest rates of N and P were added as fall band and broadcast applications, respectively. This amount of P accumulated was significantly higher compared to that of the plot where no P was applied. However, this response is confounded by rate and method of placement of nitrogen.

TABLE 7

The effect of N-P placement on dry matter yield, Tissue P concentration and P uptake of flax at flowering stage

Rates and Placement Methods		Yield (kg ha ⁻¹)	P concentration (% P)	P uptake (kg ha ⁻¹)
Nitrogen	Phosphorus			
Spring broadcast (90)	- (0)	1905 bc	0.16 a	3.1 bc
Spring broadcast (90)	With Seed (10)	2517 abc	0.15 a	3.8 abc
Spring broadcast (90)	Below Seed (10)	2738 ab	0.15 a	4.2 abc
Spring broadcast (90)	Below Seed (30)	2632 abc	0.17 a	4.4 abc
- (0)	Fall banded (20) ¹	1425 c	0.17 a	2.4 c
Fall banded (90)	Fall banded (20) ¹	2396 abc	0.16 a	3.9 abc
Fall banded (90)	Fall banded (30)	2983 ab	0.16 a	4.8 ab
Fall banded (90)	With Seed (10)	2373 abc	0.16 a	3.8 abc
Fall banded (90)	Below Seed (30)	2685 abc	0.18 a	4.7 ab
Fall banded (180)	Fall banded (30)	2383 abc	0.17 a	4.0 abc
Fall banded (180)	Fall broadcast (30)	2576 abc	0.16 a	4.2 abc
Fall banded (180)	Fall broadcast (60)	3309 a	0.17 a	5.5 a

All the figures in parentheses are rates of the respective elements in kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

¹Additional 10 kg ha⁻¹ was placed with seed

4.1.3.4 The effect of N-P placement on flax at maturity

Seed yield at maturity ranged from 855 to 1062 kg ha⁻¹ in all treatments (Table 8). These were below average yield for Manitoba. Generally yields were not significantly affected by P fertilization, rate of application or placement methods in the treatments which were to be compared. Highest yield was obtained where nitrogen (90 kg N ha⁻¹) was banded in fall and P was added as a split application (20 kg P ha⁻¹ banded in fall and 10 kg P ha⁻¹ placed with the seed). The lowest yields were obtained from the treatment where nitrogen (90 kg N ha⁻¹) was spring broadcast and P (10 kg P ha⁻¹) was placed below the seed, and where nitrogen (180 kg N ha⁻¹) was deep banded in fall and P (30 kg P ha⁻¹) was fall broadcast.

Seed P concentrations in all treatments ranged from 0.24 to 0.35 % and this range (0.11 %) in concentration was substantial but not statistically significant (Table 8). Highest concentration was observed in the treatment where the highest rate of nitrogen (180 kg N ha⁻¹) and the highest rate of P (60 kg P ha⁻¹) were added as fall band and broadcast, respectively. Lowest P concentration among P treated plots was obtained in the treatment where nitrogen (90 kg N ha⁻¹) was fall banded and P (30 kg P ha⁻¹) was placed below the seed.

Total P of the seed of flax was overall low ranging from 2.2 to 3.4 kg ha⁻¹ and this range in total P was significant (Table 8). However, no significant differences were detected between treatments that were to

be compared. Highest amount of total P in the seed was observed in the treatment where the highest rate of nitrogen (180 kg N ha^{-1}) was banded in fall and highest rate of P (60 kg P ha^{-1}) was fall broadcast. Lowest amounts were obtained in the treatments where nitrogen (90 kg N ha^{-1}) was either broadcast in spring or banded in fall and P (10 or 30 kg P ha^{-1}) was placed below the seed.

Straw yield was not significantly affected by treatments, and very low concentrations and total P were measured in the straw (Table 9). Only about 12 % of total P absorbed by the plants remained in the straw and this was an indication that optimum translocation had occurred. Straw P concentrations were about 0.02 % and total P in the straw was about 0.4 kg ha^{-1} .

Total crop yield was not profoundly influenced by treatments and there were no significant differences between treatments that had no confounding effects (Table 10). Highest crop yield was obtained in the treatment where nitrogen (90 kg N ha^{-1}) was banded in fall and P (10 kg P ha^{-1}) was placed with the seed. There was a significant response to P placed with the seed (90 kg N ha^{-1} fall banded) as compared with the treatment where no P was applied. Lowest yields among the P treated plots were obtained in the treatments where either nitrogen (90 kg N ha^{-1}) was spring broadcast and P (10 kg P ha^{-1}) was placed below the seed or where nitrogen (180 kg N ha^{-1}) was banded in fall and P (30 kg P ha^{-1}) was broadcast in fall.

Total P taken up by flax was also not significantly affected by treatments (Table 10). The treatments that had no confounding effects

did not differ substantially. Highest P uptake was observed in the treatment where the highest rate of nitrogen (180 kg N ha^{-1}) was banded in fall and highest rate of P (60 kg P ha^{-1}) was fall broadcast. Lowest P uptake among the P treated plots was obtained in the treatments where either nitrogen (90 kg N ha^{-1}) was broadcast in spring and P (10 kg P ha^{-1}) was placed below the seed or where the same amount of nitrogen was banded in fall and P (30 kg P ha^{-1}) was placed below the seed.

4.1.3.5 The effect of N-P placement on protein and oil content of flax

There were no statistical differences between treatments for both protein and oil content (Table 11). Protein content ranged from 26 to 28 % and oil content from 43 to 44 % in all treatments. The work of Schumalfuss (1963) showed an inverse relationship between protein and oil content with increasing rates of nitrogen. However, the results obtained in this experiment for protein and oil content were virtually constant for the two quality components in all treatments.

TABLE 8

The effect of N-P placement on yield, P concentration and total P of the seed of flax

Rates and Placement Methods		Yield (kg ha ⁻¹)	P concentration (% P)	Total P (kg ha ⁻¹)
Nitrogen	Phosphorus			
Spring broadcast (90)	- (0)	926 ab	0.24 a	2.2 b
Spring broadcast (90)	With Seed (10)	980 ab	0.32 a	3.2 ab
Spring broadcast (90)	Below Seed (10)	855 b	0.25 a	2.2 b
Spring broadcast (90)	Below Seed (30)	891 ab	0.28 a	2.5 ab
- (0)	Fall banded (20) ¹	993 ab	0.27 a	2.7 ab
Fall banded (90)	Fall banded (20) ¹	1062 a	0.32 a	3.3 ab
Fall banded (90)	Fall banded (30)	994 ab	0.30 a	3.0 ab
Fall banded (90)	With Seed (10)	1017 ab	0.30 a	3.0 ab
Fall banded (90)	Below Seed (30)	902 ab	0.24 a	2.2 b
Fall banded (180)	Fall banded (30)	1015 ab	0.30 a	3.0 ab
Fall banded (180)	Fall broadcast (30)	872 b	0.31 a	2.7 ab
Fall banded (180)	Fall broadcast (60)	989 ab	0.35 a	3.4 a

All the figures in parentheses are rates of the respective elements in kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

¹Additional 10 kg ha⁻¹ was placed with seed

TABLE 9

The effect of N-P placement on yield, P concentration and total P of the straw of flax

Rates and Placement Methods		Yield (kg ha ⁻¹)	P concentration (% P)	Total P (kg ha ⁻¹)
Nitrogen	Phosphorus			
Spring broadcast (90)	- (0)	1638	0.017	0.3
Spring broadcast (90)	With Seed (10)	1812	0.019	0.4
Spring broadcast (90)	Below Seed (10)	1751	0.019	0.3
Spring broadcast (90)	Below Seed (30)	2044	0.024	0.5
- (0)	Fall banded (20)'	1812	0.020	0.4
Fall banded (90)	Fall banded (20)'	1863	0.021	0.4
Fall banded (90)	Fall banded (30)	1833	0.021	0.4
Fall banded (90)	With Seed (10)	2247	0.019	0.4
Fall banded (90)	Below Seed (30)	1882	0.020	0.4
Fall banded (180)	Fall banded (30)	1819	0.022	0.4
Fall banded (180)	Fall broadcast (30)	1718	0.022	0.4
Fall banded (180)	Fall broadcast (60)	1774	0.024	0.4

All the figures in parentheses are rates of the respective elements in kg ha⁻¹
'Additional 10 kg ha⁻¹ was placed with seed

TABLE 10

The effect of N-P placement on total crop yield and P uptake of flax at maturity

Rates and Placement Methods		Total crop yield (kg ha ⁻¹)	P uptake (kg ha ⁻¹)
Nitrogen	Phosphorus		
Spring broadcast (90)	- (0)	2564 b	2.5 cd
Spring broadcast (90)	With Seed (10)	2791 ab	3.6 abc
Spring broadcast (90)	Below Seed (10)	2606 b	2.5 cd
Spring broadcast (90)	Below Seed (30)	2934 ab	3.0 abcd
- (0)	Fall banded (20) ¹	2805 ab	3.1 abcd
Fall banded (90)	Fall banded (20) ¹	2925 ab	3.7 ab
Fall banded (90)	Fall banded (30)	2826 ab	3.4 abc
Fall banded (90)	With Seed (10)	3264 a	3.4 abc
Fall banded (90)	Below Seed (30)	2784 ab	2.6 bcd
Fall banded (180)	Fall banded (30)	2833 ab	3.4 abc
Fall banded (180)	Fall broadcast (30)	2590 b	3.1 abcd
Fall banded (180)	Fall broadcast (60)	2763 ab	3.8 a

All the figures in parentheses are rates of the respective elements in kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

¹Additional 10 kg ha⁻¹ was placed with seed

TABLE 11

The effect of N-P placement on protein and oil content of flax

Rates and Placement Methods		protein content (%)	oil content ¹ (%)
Nitrogen	Phosphorus		
Spring broadcast (90)	- (0)	26	43
Spring broadcast (90)	With Seed (10)	27	43
Spring broadcast (90)	Below Seed (10)	28	43
Spring broadcast (90)	Below Seed (30)	28	43
- (0)	Fall banded (20) ²	26	43
Fall banded (90)	Fall banded (20) ²	27	44
Fall banded (90)	Fall banded (30)	27	43
Fall banded (90)	With Seed (10)	28	44
Fall banded (90)	Below Seed (30)	28	43
Fall banded (180)	Fall banded (30)	27	44
Fall banded (180)	Fall broadcast (30)	27	43
Fall banded (180)	Fall broadcast (60)	28	43

¹Seed oil analysis, courtesy of Katherine Cseres, Plant Science, DepartmentAll the figures in parentheses are rates of the respective elements in kg ha⁻¹²Additional 10 kg ha⁻¹ was placed with seed

4.1.4 Summary and conclusions

Under the conditions of this experiment response of canola and flax to applied P was very low. This was unexpected for canola at Treherne, particularly since the NaHCO_3 -extractable P level of the soil was not high. Lack of response of flax to P was not unexpected because previous research work in Manitoba has shown that flax is generally unresponsive to applied P (Racz, 1965; Stiver and Racz, 1967). Generally N-P placement methods did not substantially influence yield and P accumulation of canola and flax. The results of the experiment were affected by a poor growing season which resulted in crop water stress. However, some variability within the field may have been due to past management practices on this farm as the farmer has regularly fertilized his crops, and this research field was near an abandoned farmstead where manures may have been spread. Although the treatments had no marked effect on the quality of canola and flax, protein and oil content of canola showed an inverse relationship and this was in accordance with the results reported on rape by Appelquist (1968).

Chapter V

GROWTH BENCH EXPERIMENT 1

5.1 EFFECT OF N AND P PLACEMENT ON DRY MATTER PRODUCTION AND P ACCUMULATION OF CANOLA

5.1.1 Introduction

A growth bench experiment with canola was conducted during the winter of 1985. The objectives of the experiment were to (1) estimate the time when canola plants start absorbing fertilizer phosphorus from the various N-P placement combinations (2) evaluate methods of N-P placement in terms of yield and P accumulation (3) determine the N-carrier effect (using urea and ammonium nitrate) on P accumulation from a dual fertilizer band (4) investigate the effect of nitrogen on phosphorus absorption and yield of canola. In order to isolate fertilizer from soil phosphorus taken up by the plants, isotopic tracer methodology was employed using ^{32}P -labeled monoammonium phosphate.

5.1.2 Materials and Methods

The soil used was collected from a field at Haywood (SE36-8-6W). The soil was classified as Almasippi Gleyed-carbonated Rego black³. The selection of the site for sampling was based on available (NaHCO_3 -extractable) phosphorus concentration which was in the medium

³ Soil classification by Michalyna and Smith (1972)

range (Table 12). Soil was collected from two horizons (A and C). The surface soil approximated the plow layer (0-15 cm) and the subsurface soil was from 15-40 cm (C horizon) and approximated the subsoil. The purpose of this type of sampling was to try and simulate the field situation when plants are grown under growth bench conditions.

The soil from the two horizons (A and C) was air-dried separately, and passed through a 2-mm sieve. Each soil was mixed thoroughly prior to use. Field capacity was determined to facilitate controlled watering of the plants on a regular basis. Samples of the surface and subsurface soil were prepared for laboratory chemical analysis to characterize the soil (Table 12). The containers used were large wooden boxes measuring 46 cm long by 26 cm wide and 30 cm deep and were lined with plastic.

Seventeen kilograms of the surface and 17 kg of the subsurface soil were used in each box. The experiment consisted of 8 treatments, each replicated 3 times and the 24 boxes were arranged in a completely randomized design. All treatments received the supplemental elements K as K_2SO_4 , Cu as $CuSO_4 \cdot 5H_2O$ and Zn as $ZnSO_4 \cdot 7H_2O$ at the rates of 200, 15 and 20 kg ha^{-1} of the respective elements mixed in the surface soil. The rates of nitrogen and phosphorus used were 100 kg N ha^{-1} as urea (46-0-0) or ammonium nitrate (35-0-0) and 60 kg P ha^{-1} as ^{32}P -labeled monoammonium phosphate. Carrier-free ^{32}P (1 mC) was in the form of H_3PO_4 . The preparation of radioactive phosphorus fertilizer solution involved dissolution of appropriate amounts of the inactive monoammonium phosphate in a small volume of distilled water. The ^{32}P solution was then added and the solution was diluted to the required volume.

In the broadcast treatments which received nitrogen and phosphorus as mixed applications the elements were added to the surface soil only (0-15 cm layer). Band placement of nitrogen and phosphorus included 2.5 cm directly below, 2.5 cm below and beside (dual and separate), and 10 cm below and beside the seed. Separate bands were placed one band on each side of the seed row and were separated by 5 cm. All the treatments received phosphorus except the control which received N only.

The soil in the boxes was brought to field capacity and seeded with canola (Brassica napus L., var. Regent) in three rows of 20 cm spacing. About 20 seeds were used in each row and 4 days after emergence they were thinned to 12 to give an approximate seeding rate of 8 kg ha⁻¹. Plants were watered with distilled water starting 10 days after seedling emergence and this was done on the basis of difference in weight. Additional nitrogen was applied to all boxes at the rate of 100 kg N ha⁻¹ 30 days after emergence.

Temperature and humidity were not controlled as the experiment was conducted on the growth benches. The light intensity ranged from 300-350 microeinsteins m⁻² s⁻¹ at the surface of the crop canopy. Photoperiod was set at 16 hours.

Phosphorus uptake (activity of P in the plant in mrem hour⁻¹) was monitored over the growth period starting 4 days after the crop had emerged to 36 days from emergence using a hand held Geiger counter. This was done by passing the window of the counter over a row of crop at a close range. The activity of P in the plants was then read on the scale of the counter.

At flowering time (45 days from emergence), the above ground portions of the plants in the centre row were harvested by clipping at the soil surface. The plant materials were oven-dried at 60 °C and weighed to determine the dry matter yield. The plants were then ground in a Wiley mill and analysed for P.

TABLE 12

Some Characteristics of the soil used for Growth Bench Experiment 1

Location	Haywood
Soil series	Almasippi
Sub-group	Gleyed-Carbonated Rego black ¹
Texture	VFS
Carbonate content (0-15 cm)	High
(15-40 cm)	High
pH	8.4
Conductivity (mmhos)	0.2
NO ₃ -N (ppm)	
(0-15 cm)	3.0
(15-40 cm)	1.0
Exchangeable K (ppm)	
(0-15 cm)	272.0
(15-40 cm)	282.0
NaHCO ₃ -P (ppm)	
(0-15 cm)	9.0
(15-40 cm)	5.0
SO ₄ -S (ppm)	
(0-15 cm)	5.0
(15-40 cm)	7.0
Organic matter	4.0
Field capacity (% of dry wt.)	
(0-15 cm)	23.0
(15-40 cm)	15.0

¹Soil classification by Michalyna and Smith (1972)

5.1.3 Results and discussion

Growth bench environmental conditions although not controlled were considered adequate for plant growth. Temperatures over the growing period varied between 24 and 27 °C.

Monitoring ^{32}P activity in the plants using a hand held Geiger counter revealed that fertilizer phosphorus uptake from the phosphorus bands placed 2.5 cm below and 2.5 cm to the side of the seed row (when urea was mixed with the soil) was delayed by about 6 days compared to where both urea and phosphorus were mixed with the soil (Figure 1). This delay may be attributed to distance from the seed and the time it took the roots to concentrate into the band or the ammonium-nitrogen concentration in the monoammonium phosphate was high enough to inhibit root proliferation into the band zone. However, once the absorption of fertilizer phosphorus from the phosphorus banded 2.5 cm below to 2.5 cm to the side of the seed row started, the rate of uptake exceeded that where urea and fertilizer phosphorus were mixed with the soil. At day 36 since emergence higher ^{32}P activity was recorded in the plants which received phosphorus banded 2.5 cm below and 2.5 cm to the side of the seed row compared to where both urea and phosphorus were mixed with the soil.

Results of ^{32}P activity in canola plants showed that there was a delay in fertilizer phosphorus absorption of about 10 to 12 days where urea and phosphorus were placed in a common band 2.5 cm below and 2.5 cm to the side of the seed row or 10 cm below and 10 cm to the side of the seed row compared to where urea and phosphorus were banded 2.5 cm

directly below the seed row (Figure 2). The delay in uptake is likely due to a combination of factors including high ammonia concentration inhibiting roots from penetrating the fertilizer zone (Flaten and Racz, 1982), distance of band placement from the seed row and spatial relationship of canola roots with the bands. However, following delay in fertilizer absorption from the dual bands placed 2.5 cm below and 2.5 cm to the side of the seed row or 10 cm below and 10 cm to the side of the seed row, canola plants absorbed fertilizer phosphorus more rapidly than in the treatment where urea and phosphorus were banded 2.5 directly below the seed row. At day 36 since emergence the activity of ^{32}P in the plants where urea and phosphorus were banded in a common band either 2.5 cm below and 2.5 cm to the side of the seed row or 10 cm below and 10 cm to the side of the seed row was higher than that of the plants where urea and phosphorus were banded 2.5 cm directly below the seed row.

A comparison of ^{32}P activity in the plants where urea or ammonium nitrate was dual banded with phosphorus showed that there was a 10 day delay in fertilizer phosphorus absorption for the plants where urea and phosphorus were dual banded compared to that where ammonium nitrate and phosphorus were dual banded 2.5 cm below x 2.5 cm to the side of the seed row (Figure 3). However, once the plants started absorbing fertilizer phosphorus from the urea band, the rate of absorption was higher than that where ammonium nitrate was applied. Similarly, there was a 10 day delay in fertilizer phosphorus absorption by the plants from the band where urea was dual banded with phosphorus compared to where the two fertilizers were banded separately (2.5 cm below and 2.5 cm to the side of the seed row). This delay may be associated with the

toxic levels of ammonia in the dual band which may have hindered roots from penetrating the bands in the initial stages of plant growth.

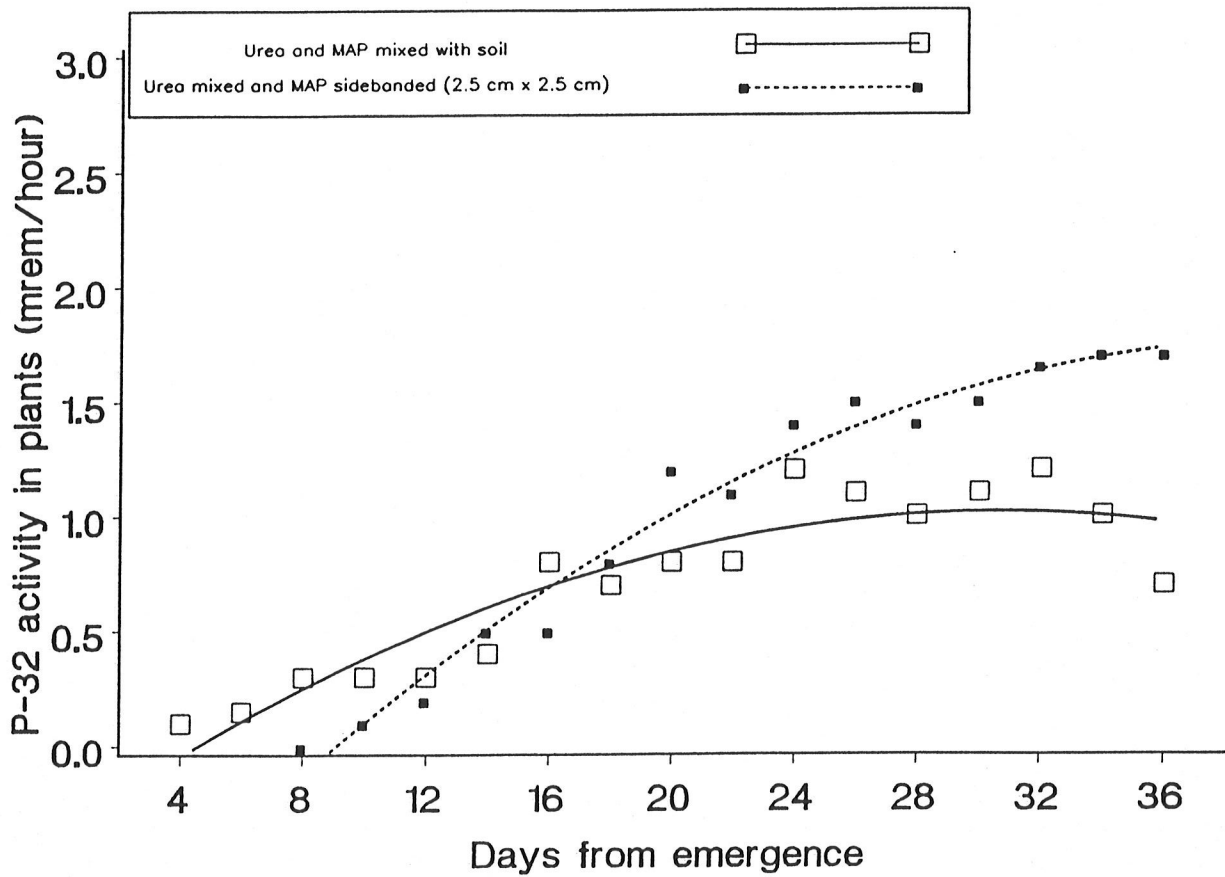


Figure 1: The effect of N-P placement on ^{32}P activity in plants (Mixed vs Sidebanded)

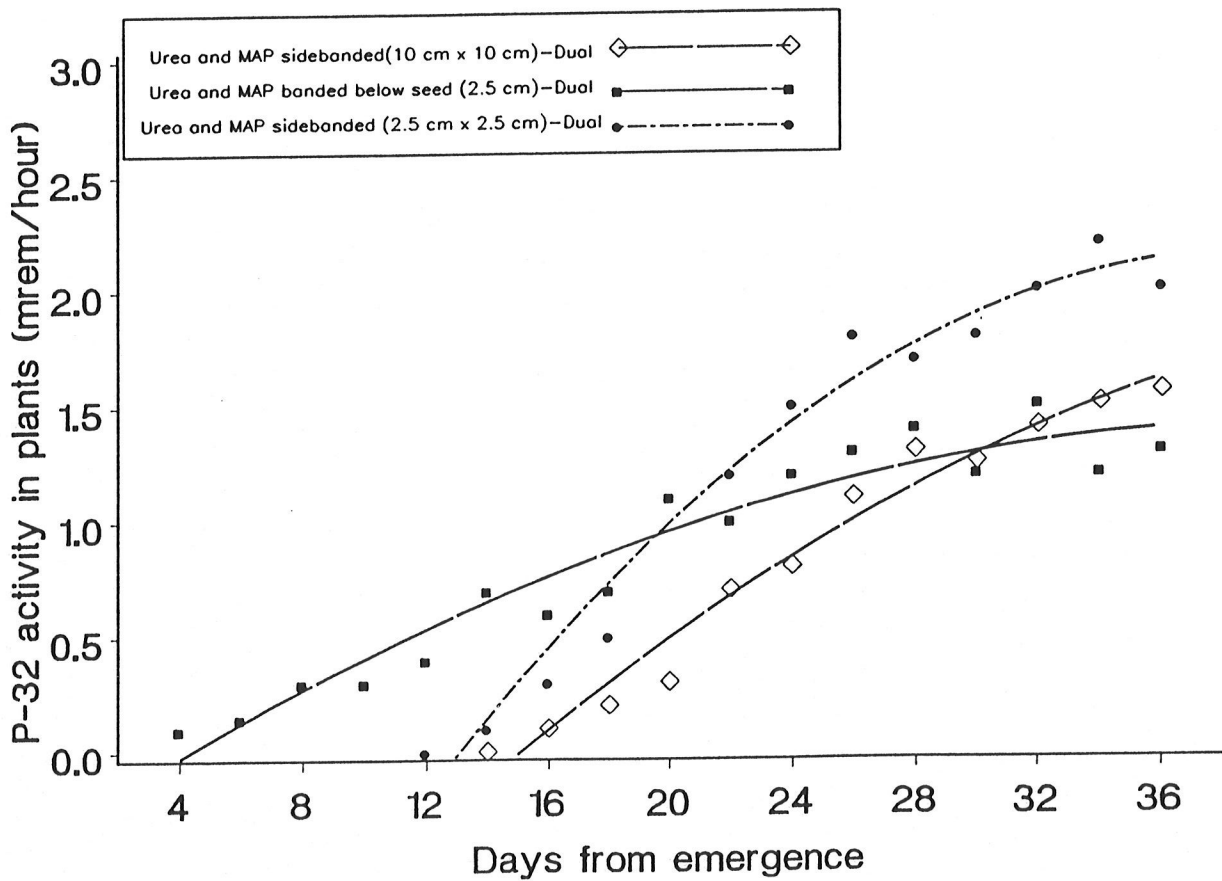


Figure 2: The effect of N-P placement (2.5 cm directly below vs 2.5 cm below x 2.5 cm to the side vs 10 cm below x 10 cm to the side) on ^{32}P activity in plants

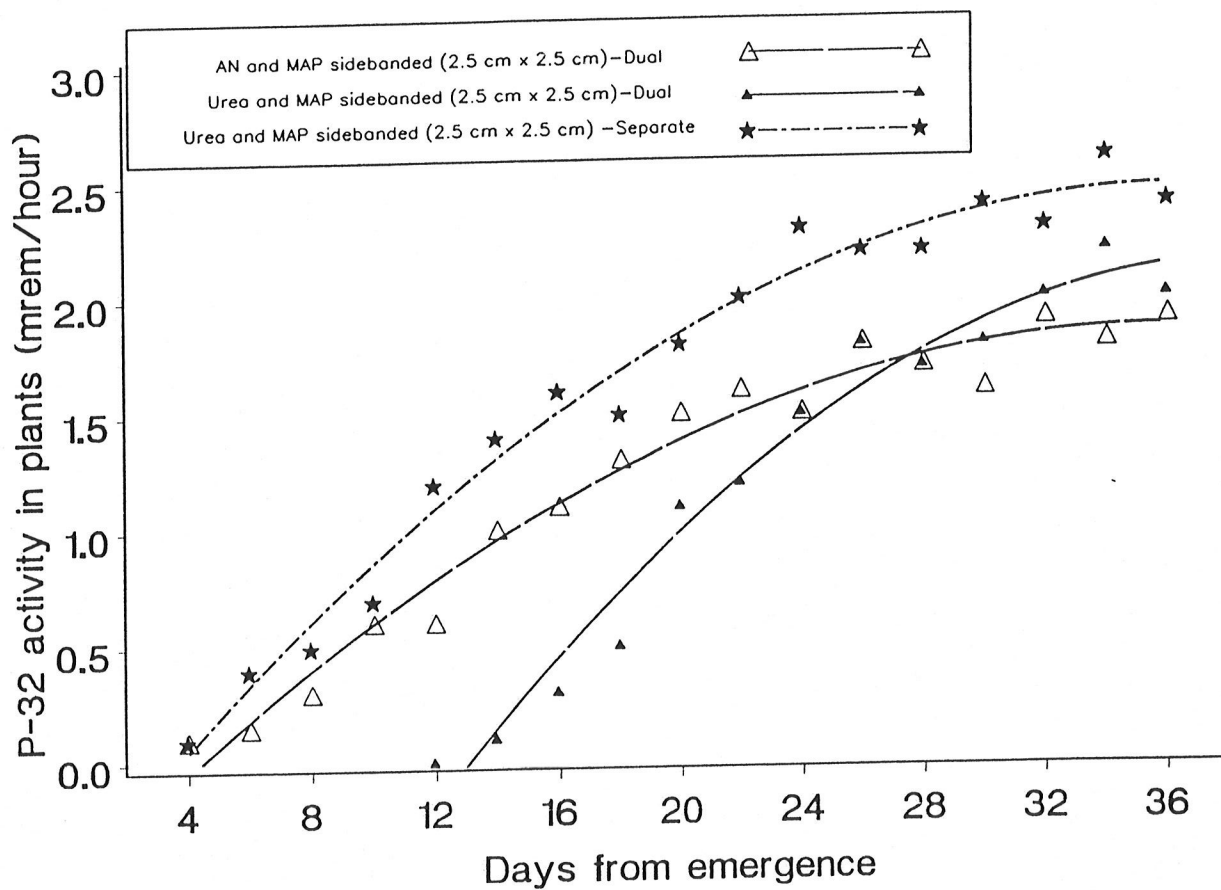


Figure 3: The effect of N-P placement (NH_4NO_3 vs urea or urea dual vs urea separate) on ^{32}P activity in plants

Application of P greatly increased yields of canola (Table 13). Only in the treatment where N and P were placed 2.5 cm directly below the seed was the increase not significant. Highest yields were obtained from the treatments in which both N and P were sidebanded close to the seed. Sidebanding of N and P 10 cm below and to the side of the seed produced considerably less dry matter than sidebanding close to the seed indicating that the fertilizer was too far away from the seed and was not adequately utilized by the plants by flowering time. Sidebanding N separate from P but close to the seed resulted in more dry matter than where N and P were dual banded close to the seed. The difference in dry matter yield between separate N and P and dual bands was likely related to the delay in uptake of fertilizer P (Figures 2 and 3). High levels of ammonia in the dual bands could have inhibited root penetration into the fertilizer reaction zone causing time lag in uptake (Flaten and Racz, 1982).

When N was mixed into the soil, placement of P 2.5 cm below and to the side of the seed row resulted in significantly higher fertilizer P uptake compared to N and P added as a mixed application (Table 13). Mixing fertilizer phosphorus with the soil allows more soil-fertilizer contact resulting in more fertilizer reacting with soil components, especially calcium and magnesium in calcareous soils, to form relatively insoluble phosphate compounds. Since the soils were highly carbonated and had a high pH (8.4) the significant difference in fertilizer P uptake between mixed P and banded P could be well explained on this basis. Also, mixed application allows distribution of fertilizer

phosphorus in a large volume of soil. Since plants have been found to derive most of the phosphorus from within the rhizosphere (Barber, 1962; Lewis and Quirk, 1967) due to the relative immobility of phosphorus in the soil system, lack of root concentration in the entire soil volume would likely reduce the amount of phosphorus absorbed by plants. Significantly higher P uptake occurred where nitrogen and phosphorus were placed together 2.5 cm below and to the side of the seed row compared to placement 2.5 cm directly below the seed row. The low fertilizer P values obtained when N and P were placed directly below the seed compared to where N and P were placed 2.5 cm below and to the side of the seed, are consistent with the yield data. This gave an indication that there was a positional advantage of sidebanding N and P as compared to banding the two fertilizers directly below the seed. The difference between placement of N and P 2.5 cm below and to the side of the seed and 2.5 cm directly below the seed may probably be due to differences in the spatial relationships of the developing canola root system and the fertilizer reaction zone (Sadler et al., 1981). There was no advantage in terms of P uptake attributed to nitrogen source. Placement of urea or ammonium nitrate and phosphorus in a common band 2.5 cm below and to the side of the seed row resulted in comparable amounts of P taken up. Placement of N and P 2.5 cm below and to the side of the seed (close to the seed) gave higher fertilizer P uptake compared to placement 10 cm below and to the side of the seed (away from the seed), indicating the fertilizer may have been too far away for early root interception of the fertilizer in the band. The time lag in uptake during early stages of plant growth (Figure 2) may have contributed to the difference between placement of N and P close to the

seed and away from the seed. Higher fertilizer P uptake was obtained when N and P were placed in separate bands 2.5 cm below and to the side of the seed row compared with placement of the two fertilizers in a common band. This difference was, however, not statistically significant. The difference between separate and dual banding of N and P could be attributed to high levels of ammonia in the dual band (Flaten and Racz, 1982). Ammonia may have inhibited root penetration into the fertilizer zone and thus delayed fertilizer P uptake during the early stages of plant growth. This is also evidenced by the data of plant activity (mrem hour^{-1}) obtained using a hand held Geiger Counter (Figure 3).

Soil phosphorus uptake (Table 13) was increased by P fertilization in most treatments; however, the increases were not significant where N and P were either added as mixed applications or banded 2.5 cm directly below the seed row. Significantly higher soil phosphorus uptake was observed in the treatment where N and P were placed together 2.5 cm below and to the side of the seed row compared with either mixed application or placement 2.5 cm directly below the seed row. Although higher soil P uptake was observed in the treatment where urea and P were banded together 2.5 cm below and to the side of the seed row compared with that where ammonium nitrate was used, the difference was not significant. Similar results were obtained when N and P were placed 2.5 cm below and to the side of seed (close to the seed) in separate bands or 10 cm below and to the side of seed (away from the seed) in a common band.

The relative effectiveness of the various N-P placement methods in increasing total P uptake followed essentially the same pattern as for yield (Table 13). Phosphorus fertilization significantly increased total phosphorus taken up by canola in all treatments, except where N and P were banded 2.5 cm directly below the seed row. When N was mixed into the soil, placement of P 2.5 cm below and to the side of the seed row resulted in higher total P uptake compared to mixed application, but the difference was not statistically significant. Despite the fact that placement of urea-N and P 2.5 cm below and to the side of the seed row resulted in higher total P uptake compared to the treatment where ammonium nitrate was used as N source, the difference was not substantial. Similarly, placement of N and P 10 cm below and to the side of the seed (far from the seed) resulted in uptake that was not significantly different from that obtained where N and P were banded 2.5 cm below and to the side of the seed (close to the seed). Placement of N and P either together or separately 2.5 cm below and to the side of the seed row, resulted in comparable amounts of total P taken up by canola. These were the highest uptake values obtained compared to those of other treatments that received fertilizer P.

The proportion of phosphorus derived from fertilizer was not significantly affected by method of N-P placement (Table 13). However, placement of N and P 2.5 cm below and to the side of seed row in separate bands significantly increased the proportion of P in the plants that was derived from fertilizer compared to placement of N and P 2.5 cm below and to the side of seed row in dual bands or as mixed application. The delay in fertilizer P uptake (Figures 2 and 3) which was probably

due to high levels of ammonia in the dual band, may account for the great difference observed between the separate and the dual bands in terms of the proportion of P derived from fertilizer.

TABLE 13

Effect of N and P placement on P uptake and Dry matter production of canola at flowering time

Method of fertilizer placement		Dry Matter (gm/box)	Pdff (%)	Fertilizer P uptake (mg/box)	Soil P uptake (mg/box)	Total P (mg/box)
Nitrogen ¹	Phosphorus					
Mixed	Control	5.8 c	-	-	14.4 c	14.4 c
Mixed	Mixed	15.7 ab	25.2 b	13.6 d	40.6 bc	54.2 b
Mixed	Sideband ²	15.6 ab	30.4 ab	22.9 bc	52.6 ab	75.5 ab
Dual bands						
Below seed	Below seed ³	11.1 bc	32.2 ab	16.6 cd	35.5 bc	52.1 bc
Sideband	Sideband ²	18.8 ab	26.2 b	26.4 ab	75.0 a	101.4 a
Sideband (AN)	Sideband ²	19.0 ab	30.3 ab	24.7 bc	56.5 ab	81.2 ab
Sideband	Sideband ⁴	14.6 ab	31.7 ab	22.6 bc	48.8 ab	71.4 ab
Separate Bands						
Sideband	Sideband ²	20.5 a	36.9 a	34.7 a	61.9 ab	96.6 a

AN=Ammonium Nitrate

Pdff=Phosphorus derived from fertilizer

¹Nitrogen source was urea (46-0-0) except for the treatment where ammonium nitrate (35-0-0) was applied²Placed 2.5 cm below and 2.5 cm beside seed row³Placed 2.5 cm directly below seed row⁴Placed 10 cm below and 10 cm beside seed row

Figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

5.1.4 Summary and conclusions

This study was conducted under a semi-controlled environment in the growth room. The data obtained during the growing period using a hand held Geiger counter indicates that canola plants started absorbing fertilizer phosphorus at an early stage of plant growth. However, this varied with N-P placement combinations. Canola plants in the treatments where urea and phosphorus were mixed with the soil, banded 2.5 cm directly below the seed row, sidebanded separately (2.5 cm below and 2.5 cm to the side of seed row) or where ammonium nitrate and phosphorus were sidebanded together (2.5 cm below and 2.5 cm to the side of the seed row) started absorbing fertilizer phosphorus soon after emergence. Where urea and phosphorus were sidebanded together (2.5 cm below and 2.5 cm to the side of the seed row or 10 cm below and 10 cm to the side of the seed row), fertilizer phosphorus absorption was delayed.

Generally there was a response to phosphorus fertilization in terms of dry matter production and phosphorus uptake in all treatments; however, there were no substantial differences among the treated plants, for the treatments that had no confounding effects. Neither urea nor ammonium nitrate markedly influenced dry matter production or phosphorus uptake. Similarly, urea in a common band with phosphorus was not effective in substantially increasing dry matter production or phosphorus uptake. Placement of nitrogen and phosphorus directly below the seed row (2.5 cm) resulted in the lowest dry matter production and phosphorus uptake among the treatments which received urea and phosphorus placed in common bands.

Chapter VI

FIELD EXPERIMENT 2

6.1 EFFECT OF N AND P PLACEMENT ON YIELD AND P UPTAKE OF CANOLA AND FLAX AT VARIOUS STAGES OF GROWTH

6.1.1 Introduction

Due to unfavourable growing season conditions experienced in 1984, the preliminary study on the effect of N-P placement methods and rates of application described in chapter 4 did not provide useful information on the effectiveness of the various N-P placement combinations. Hence, the next field study conducted in 1985 was slightly modified with special emphasis on the time when canola and flax plants start absorbing fertilizer phosphorus from the various N-P placement combinations. Previous research work has shown the importance of early availability and absorption of phosphorus by plants. Boatwright and Viets (1966) in solution culture studies with wheat found that early utilization of phosphorus resulted in substantial yield increase and promoted tillering and secondary root development.

This study was initiated on Manitou CL at Kaleida (NW9-2-8W). The objectives of the experiment were to (1) evaluate N-P placement methods in terms of yield and phosphorus uptake of canola and flax, (2) monitor dry matter production and phosphorus uptake at various stages of growth and calculate phosphorus recovery by the difference method, (3) determine the effect of nitrogen on phosphorus absorption and yield of

canola and flax. The difference method (Indirect method) was employed in this study because ^{32}P was not used. The calculated phosphorus recovery obtained by the above method at various stages of growth was intended to estimate the variation of the treatments and the time when plants start absorbing fertilizer phosphorus with respect to N-P placement combinations. The site selected was medium in NaHCO_3 -extractable phosphorus concentration (Table 14). The experimental plots were set up on a field which was planted to wheat the previous year.

6.1.2 Materials and Methods

The experiment consisted of 6 treatments each replicated six times and the experimental design employed was a randomized complete block. The treatments, replications and design were identical for both canola and flax. The size of the plots was 3 m wide by 6 m long providing for 16 rows of 18 cm spacing. This allowed for adequate plant sampling for dry weight and P uptake at various growth stages and for final harvest. The treatments are shown in Table 15.

Phosphorus application was done at the rate of 10 kg P ha^{-1} as monoammonium phosphate (11-51-0). All treatments received nitrogen in the form of urea (46-0-0) at the rate of 200 kg N ha^{-1} as broadcast application, except for the treatment where N and P were placed in common bands to a depth of 10 cm and 36 cm spacing between bands. Deep bands were placed using a multi-row bander equipped with fertilizer application knives set 36 cm apart.

After the plots were staked, sampling was done on selected plots for chemical characterization of the soil (Table 14). The sequence of fertilizer application in all the respective treatments was deep band placement of N and P, broadcast P, and broadcast N. Then the plots were disced to incorporate the broadcast fertilizers to a shallow depth of about 7.5 cm. Discing was followed by spike harrowing to make a good seedbed. The treatments which received phosphorus placed below seed were then administered using the fertilizer-seed drill with a V-belt combination. Fertilizer was placed at a depth of 4 cm below the soil surface.

Canola (Brassica napus L., var. Westar) and flax (Linum usitatissimum L., var. Dufferin) were seeded on May 8th to a depth of 1.5 cm from the surface at the rates of 8 kg ha⁻¹ and 40 kg ha⁻¹ respectively. Due to very low air temperatures that spring, it took a longer than normal time for the soils to warm up and as a result emergence of the crops was delayed by about a week.

Weed growth was not a problem on the plot area at early growth stages of the crops. Canola competed effectively with the few broadleaf weeds that emerged later. Flax, however, was sprayed with Bucril M at the recommended rate of 1.25 L ha⁻¹.

Harvesting of the above ground portions started 20 days after emergence, when canola was at rosette stage and flax at the six leaf stage. The area harvested for both crops was 30 cm by 4 centre rows (0.3 m x 0.72 m). The first three harvests were taken on a weekly basis and the subsequent harvests after every two weeks. Harvest descriptions are shown in Table 16.

Plant samples were oven-dried at 60 °C and weighed to determine dry matter yield. The dry plant materials were then ground in a Wiley mill and digested for P analysis.

The final harvest was done at maturity, 14 weeks from the time of emergence. The area harvested for canola was 1 m x 0.72 m (4 centre rows) and for flax 2 m x 0.72 m (4 centre rows). The samples were air-dried, weighed, threshed and yield components calculated. Straw samples were ground in Wiley mill and digested for P analysis but the digestion of grain samples was done on intact grain. Phosphorus recovery was calculated using the difference method equation;

$$\text{Phosphorus recovery (\%)} = \frac{\text{TP1} - \text{TP0}}{\text{Applied P}} \times 100$$

TP0= Total plant phosphorus in untreated plots

TP1= Total plant phosphorus in treated plots

TABLE 14

Some Characteristics of the soil used for field Experiment 2

Location	Kaleida
Soil series	Manitou CL
Soil type	Black chernozem ¹
Texture	CL
Organic Matter (%)	6.6
Conductivity (mmhos)	0.2
pH	6.5
Exchangeable K (ppm to 15 cm)	364.0
NO ₃ -N (Kg ha ⁻¹ to 120 cm)	275.0
NaHCO ₃ _P (ppm to 15 cm)	9.0
SO ₄ -S (kg ha ⁻¹ to 60 cm)	21.0
Carbonate content	VL

¹Black chernozem developed on shale glacial till (Soil classification by Ellis and Shafer (1943))

TABLE 15

List of treatments in field experiment 2: Effect of N-P placement on yield and P uptake of canola and flax

Treatment #	Nitrogen ¹	Phosphorus ²
1	Broadcast	Control
2	Broadcast	Broadcast
3	Broadcast	Deep banded ³
4	Deep banded	Deep banded (Dual)
5	Broadcast	With seed
6	Broadcast	Below seed ⁴

¹Nitrogen was applied at the rate of 200 kg N ha⁻¹ as urea (46-0-0)

²Phosphorus was applied at the rate of 10 kg P ha⁻¹ as monoammonium phosphate (11-51-0)

³Deep bands were placed 10 cm below seeding level and 36 cm apart

⁴Placed 2.5 cm below the seed row

All broadcast applications were incorporated to a depth of 7.5 cm

TABLE 16
 Descriptions of harvests

Harvest	Date	Days from emergence	Canola	Flax
			Growth stage	Growth stage
Harvest1	June 10	20	Rosette	Six-leaf
Harvest2	June 19	29	Rosette	Vegetative
Harvest3	June 26	36	Stem elongation	Vegetative
Harvest4	July 1	41	Flowering (start)	Vegetative
Harvest5	July 15	55	Flowering (complete)	Flowering
Harvest6	July 29	69	Pod filling	Boll Filling
Harvest7	August 27	98	Maturity	Maturity

6.1.3 Results and discussion

6.1.3.1 Effect of N and P placement on dry matter production (kg ha^{-1}) of canola at various stages of growth

Growing conditions for the crops at the Kaleida site were generally good. Soils were fairly moist at seeding time and there was enough rainfall over the growing season to maintain the soils moist, such that the plants showed no moisture stress at any particular time. Temperatures were generally cool and conducive for plant growth. The soils contained 9 ppm of NaHCO_3 -extractable P (Table 14), which is considered to be medium by the Manitoba Provincial Soil Testing Laboratory. However, according to the correlation of NaHCO_3 -extractable P to plant response to added phosphorus by Olsen (1954), plants grown on soils with this P status may or may not respond to added phosphorus. The soils contained $275 \text{ kg NO}_3\text{-N ha}^{-1}$ to a depth of 120 cm, which was very high (Table 14).

Yields in the first 20 days after emergence were higher on the fertilized plots compared to the control plot (Table 17). This was an indication that P fertilization was effective in increasing yield. However, the yield increase was not significant in all treatments except where P was added as a broadcast application. Yields did not differ significantly among treatments that received P, indicating that at the early growth stage, placement of P was not effective. Soils were medium in NaHCO_3 -extractable P and this may explain the lack of effect of P

In the control plots, yields for the growth period beginning 20 days since emergence increased from 592 to 8742 kg ha^{-1} over a 49 day period. At maturity the control plot yielded 2480 kg ha^{-1} of seed (Table 17),

which was an above average yield and reflects a generally good soil fertility level, favourable growing season temperatures and soil moisture status. Straw yields were 2.4 times greater than seed yields indicating a lush vegetative growth. That may be explained by the extremely high N status of the soil.

For the same period, treatments where P was broadcast progressed from 935 to 9648 kg ha⁻¹ over the subsequent 49 day period (Table 17). At 20 and 36 days since emergence the yields were significantly higher than those of the control plot. At day 29, 41, 55, and 69 since emergence, the yields were higher than those of the control plot but the difference was not statistically significant. Seed yield at maturity was 2894 kg ha⁻¹, which although not statistically significant, was higher than that of the control plot. Total dry matter yield at maturity was 984 kg ha⁻¹ higher than that of the control plot, however, this difference was also not significant.

In the plots which received P as a deep band application prior to planting, the yields after 20 days from emergence increased from 762 to 9144 kg ha⁻¹ over a 49 day period (Table 17). The yields in this plot were generally lower than those obtained in the plot where P was broadcast, although the difference was not significant. Also, these yields were not significantly different from those of the control plot, except 36 days after emergence. Seed yield at maturity was 2551 kg ha⁻¹ which was lower than that of the treatment where P was broadcast but higher than that of the control. These differences in yield were not statistically significant. Total dry matter production at maturity was less than that of the treatment where P was broadcast but higher than that of the control, although the differences were not significant.

For the treatment which received nitrogen and phosphorus placed together in deep bands prior to planting (dual bands), yields after 20 days from emergence increased from 639 to 9020 kg ha⁻¹ over a 49 day period (Table 17). The yields were lower than those of the treatment where P was broadcast but comparable to those of the treatment where P was deep banded alone. The explanation for the lower yields in treatments where P was deep banded either alone or in combination with N is associated with the lower plant density that was observed on these plots and was attributed to soil disturbance. The deep banding operation that was done prior to planting resulted in a loose soil and deeper planting than was desired. This caused poor crop emergence. Seed yield at maturity was 2278 kg ha⁻¹ which was the lowest of all treatments. Straw yields were 2.6 times greater than seed yield indicating a luxurious growth due to the high N levels in the soil. Total dry matter yield at maturity was less than that of the treatment where P was broadcast but comparable to that of the control plot. However, statistical analysis showed no substantial yield differences between the treatment where P was broadcast and that where P was banded in a common band with N.

Where P was placed with the seed, yields after 20 days from emergence increased from 827 to 10396 kg ha⁻¹ over a 49 day period (Table 17). Yields were always higher than those obtained in the control plot and the treatments where P was either banded alone or together with nitrogen but these differences were not significant. Generally the yields were comparable to those obtained in the treatment where P was broadcast. Seed yield at maturity was 3186 kg ha⁻¹ and was significantly higher

than the yields in the plots where P was deep banded together with nitrogen or placed below seed and the control. Total dry matter production at maturity was highest compared to other P placement methods and was significantly different from the yields in the plots where P was either placed below seed, deep banded alone, deep banded together with nitrogen or control plot. The better performance of the crop where P was placed with seed may be attributed to greater positional availability of phosphorus during the early stage of plant growth. This is also evidenced by the fact that the plots showed significant visual differences at early stage of growth (Figure 4).

Where P was placed below seed, the yields after 20 days from emergence increased from 618 to 9048 kg ha⁻¹ over a 49 day period. Yields were always higher than those of the control plot, however, the difference was not significant except at the third harvest (36 days from emergence). Between 29 and 55 days from emergence, the yields were comparable to those obtained from the plots where P was broadcast or placed with the seed, but higher than those of the treatments where P was deep banded alone or together with nitrogen. Seed yield at maturity was 2483 kg ha⁻¹, which was identical to the yield obtained in the control plot but significantly lower than that of the treatment where P was placed with seed. Straw yields were not significantly affected by either P fertilization or placement methods. There was a decline in total dry matter yield at maturity in all the treatments. This decline may be due in part to loss of leaves through senescence.

TABLE 17

Effect of N and P placement on dry matter production (Kg ha⁻¹) of canola at various growth stages

Method of P placement ¹	Days from emergence								
	20	29	36	41	55	69	Maturity		
							Seed	Straw	Total
Control	592 b	1479 a	2491 c	3669 a	6683 a	8742 a	2480 b	5836 a	8316 b
Broadcast	935 a	1892 a	3356 ab	4401 a	7532 a	9648 a	2894 ab	6406 a	9300 ab
Deep band	762 ab	1596 a	3255 ab	3889 a	6503 a	9144 a	2551 ab	5863 a	8414 b
Dual band ²	639 ab	1503 a	2768 bc	3547 a	6686 a	9020 a	2278 b	5903 a	8180 b
With seed	827 ab	1926 a	3308 ab	4427 a	7665 a	10396 a	3186 a	6713 a	9900 a
Below seed	618 ab	1782 a	3380 a	4332 a	7493 a	9048 a	2483 b	5634 a	8116 b

¹Nitrogen was added in a separate operation as a broadcast application²Nitrogen and Phosphorus were placed together in deep bandsRate of N=200 kg ha⁻¹, Rate of P=10 kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

Figure 4: Response of canola to P placed with the seed at early stage of growth as compared to the control



Control



With seed

6.1.3.2 Effect of N and P placement on tissue P concentration (% P) of canola at various stages of growth

Tissue P concentrations ranged from 0.43 to 0.56 % 20 days after emergence and 0.12 to 0.18 % 69 days after emergence (Table 17). Concentrations at flowering stage (day 41) ranged from 0.34 to 0.40 % which is considered to be in the sufficiency range according to the interpretive guidelines used by the Manitoba Provincial Soil Testing Laboratory⁴. There was a general decrease in tissue P concentrations in all the treatments from the first harvest (20 days from emergence) to 69 days from emergence. The decrease in concentration was due to the dilution effect as a result of increase in dry matter production noted in Table 16. Tissue P concentrations were always higher on P treated plots indicating that P was being recovered from added fertilizer regardless of position. At day 20 and 29 from emergence significantly high tissue P concentrations were obtained in the treatment where P was deep banded alone, compared to the treatment where P was broadcast and the control plot. At day 69, P concentrations in all the treatments were significantly greater than those of the control plot indicating response to P fertilization. Similar trends were noticed at maturity in seed P concentrations. Significantly high concentrations were obtained in the treatments where P was deep banded together with nitrogen or placed below the seed compared with the control, however, P concentrations among all the P placement methods were not significantly different from one another. Very low concentrations of P ranging from 0.03 to 0.04 % were measured in the straw which indicated that most of

⁴ Interpretive Guidelines for plant tissue analysis used by the Manitoba Provincial Soil Testing Laboratory, June 1982, Department of soil science, University of Manitoba, Winnipeg, Manitoba.

the P taken up (82 to 86 % of total P) by the plants was translocated to the seed.

TABLE 18

Effect of N and P placement on tissue P concentration (%) for canola at various growth stages

Method of P placement ¹	Days from emergence							
	20	29	36	41	55	69	Maturity	
							Seed	Straw
Control	0.43 c	0.38 b	0.33 a	0.34 a	0.17 a	0.12 b	0.31 b	0.03 a
Broadcast	0.43 c	0.40 b	0.42 a	0.40 a	0.23 a	0.18 a	0.47 ab	0.04 a
Deep band	0.56 a	0.53 a	0.41 a	0.37 a	0.26 a	0.18 a	0.48 ab	0.04 a
Dual band ²	0.54 ab	0.46 ab	0.37 a	0.37 a	0.23 a	0.17 a	0.52 a	0.04 a
With seed	0.51 abc	0.39 b	0.43 a	0.39 a	0.24 a	0.18 a	0.45 ab	0.03 a
Below seed	0.45 bc	0.44 ab	0.37 a	0.36 a	0.22 a	0.18 a	0.53 a	0.04 a

¹Nitrogen was added in a separate operation as a broadcast application²Nitrogen and Phosphorus were placed together in deep bandsRate of N=200 kg ha⁻¹, Rate of P=10 kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

6.1.3.3 Effect of N and P placement on phosphorus accumulation (kg ha^{-1}) of canola at various growth stages

Total phosphorus uptake is a function of dry matter yield and tissue P concentration. The trends observed in yield and tissue P concentration data (Tables 17 and 18) are reflected in P uptake data shown in Table 19.

Phosphorus uptake in the first 20 days after emergence was generally higher in the P treated plots compared with that of the control plot and indicated that P fertilization was effective in increasing P uptake. However, the increase was not significant. Among the P treated plots, placement of P below the seed resulted in the lowest uptake at this stage of plant growth. The low P uptake was consistent with low yields obtained 20 days after emergence (Table 17). The reason for the low yield obtained at that stage was not evident but may be related to root distribution and positional availability of added phosphorus at that stage of plant growth.

After 20 days from emergence phosphorus uptake on the control plot increased from 2.51 to 12.31 kg ha^{-1} over the next 21 days and declined thereafter until maturity. The decline in uptake may be attributed to loss of P through leaf senescence. Phosphorus uptake was lower than that of the P treated plots although not consistently significant indicating P was recovered from added fertilizer.

Where phosphorus was broadcast, uptake increased from 4.04 to 17.70 kg ha^{-1} after 20 days over the subsequent 35 day period and decreased thereafter until maturity. By flowering stage P uptake had reached a maximum. The amounts of P taken up were higher than those in the

control plot although not always significantly. Significantly high uptake compared with those of the control plot was observed on days 55 and 69.

After 20 days from emergence, phosphorus uptake on the plots where P was preplant deep banded alone increased from 4.12 to 16.85 kg ha⁻¹ over the next 35 day period and decreased thereafter to maturity. The amounts of P taken up were always not significantly different from those in the treatment where P was broadcast but were significantly higher than those in the control plot 29, 55, and 69 days after emergence.

Where phosphorus was deep banded in combination with nitrogen, uptake increased from 3.49 to 15.59 kg ha⁻¹ after 20 days from emergence over a 35 day period. The amounts taken up were generally lower than those of the treatments where P was either broadcast or deep banded alone although the difference was not significant. However, P uptake was higher than that of the control plots. The amount of P contained in the seed was 11.85 kg ha⁻¹ and was the lowest amount realized among P treated plots. This was consistent with the low seed yields obtained in this treatment (Table 17) and may be explained by the low plant density observed due to poor crop emergence. The banding operation caused soil disturbance and resulted in deeper seeding than was desired.

Where phosphorus was placed with the seed, uptake increased from 4.22 to 19 kg ha⁻¹ after 20 days from emergence over the subsequent 35 day period. The amount of phosphorus taken up were generally comparable to those of the treatment where P was broadcast but higher than those of the treatments where P was either deep banded alone or in combination

with N. High uptake obtained on this plot may be related to the positional advantage of placing P with the seed. Absorption of phosphorus by canola has been found to occur rapidly during very early stages of growth (Bailey, 1982a,). Canola plants in this plot may have benefited from the P fertilizer placed with the seed during early stages of plant growth.

After 20 days from emergence, P uptake on the plots where phosphorus was placed below the seed increased from 2.78 to 16.17 kg ha⁻¹ over a 35 day period. After 36 days uptake was generally lower than that of the plots which received P placed with the seed or broadcast but comparable to that obtained in the plots where P was deep banded alone or in combination with nitrogen.

Total amount of P contained in the seed were higher for the P treated plots compared with those of the control (Table 19). Significantly high amounts of total seed P were obtained when P was placed with the seed compared with those of the control plot. However, there were no significant differences observed among P placement methods in terms of total seed P. The proportion of seed P (% of total P) ranged from 82 % for the control plot to 88 % for the treatment where P was placed with the seed. The amounts of P contained in the straw ranged from 1.75 to 2.56 kg ha⁻¹ and the differences among treatments were not significant. Most of the P taken up by canola was translocated to the seed.

There was a decline in P uptake in all treatments after 55 days from emergence. This decline in P uptake may be associated with loss of leaves through senescence.

Total phosphorus uptake at maturity exhibited similar trends observed in amounts of P contained in the seed. Higher amounts were obtained from the plots where P was added compared to the control, however, the differences were not statistically significant in all treatments, except where P was placed with the seed.

TABLE 19

Effect of N and P placement on P accumulation (Kg ha⁻¹) of canola at various growth stages

Method of P placement ¹	Days from emergence								
	20	29	36	41	55	69	Maturity		
							Seed	Straw	Total
Control	2.51 a	5.51 b	8.28 a	12.31 a	11.17 b	10.59 b	7.74 b	1.75 a	9.49 b
Broadcast	4.04 a	7.66 ab	14.07 a	17.54 a	17.70 a	17.29 a	13.74 ab	2.56 a	16.30 ab
Deep band	4.12 a	8.42 a	13.47 a	14.57 a	16.85 a	16.57 a	12.25 ab	2.35 a	14.60 ab
Dual band ²	3.49 a	6.97 ab	10.29 a	13.29 a	15.59 a	15.08 ab	11.85 ab	2.36 a	14.21 ab
With seed	4.22 a	7.41 ab	14.46 a	17.52 a	19.00 a	18.70 a	14.49 a	2.01 a	16.50 a
Below seed	2.78 a	7.93 ab	12.42 a	15.80 a	16.17 a	16.01 a	13.27 ab	2.25 a	15.52 ab

¹Nitrogen was added in a separate operation as a broadcast application²Nitrogen and Phosphorus were placed together in deep bandsRate of N=200 kg ha⁻¹, Rate of P=10 kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

6.1.3.4 Effect of N and P placement on fertilizer P recovery (% of applied P) by canola at various growth stages

Phosphorus recovery (Table 20) was calculated using the difference method. The method is applicable on the assumption that (1) plants in both untreated and treated plots absorb soil phosphorus at the same rate, (2) lack of fertilizer phosphorus in the untreated plants does not affect the physiology of the plants, and (3) treated plants do not differentiate between soil and fertilizer phosphorus. Because the above assumptions are only approximations, the method is subject to errors and is not as accurate as radiotracer technique using ^{32}P . However, in this experiment the difference method was employed.

Highest amount of phosphorus recovered were obtained in the plants where P was placed with the seed. The superiority of P placement with the seed in terms of fertilizer P utilization over other P placement methods was consistent at all stages of plant growth except 29 days after emergence. Similar trends in this treatment were observed for dry matter production (Table 17) and phosphorus accumulation (Table 19). This was attributed to early positional availability of P placed with the seed.

Second highest amounts of phosphorus recovered were first observed in the plants harvested 29 days after emergence where phosphorus was added as a broadcast application.

Amounts of phosphorus recovered by plants in the plots where phosphorus was deep banded alone were generally higher than those observed in the plants where phosphorus was banded 2.5 cm below the seed except 55 and 98 (maturity) days after emergence since emergence.

Lowest phosphorus recovery was observed in the plants where nitrogen and phosphorus were deep banded together. These amounts of phosphorus recovered were substantially lower compared to those observed in the plants where phosphorus was singly deep banded except 69 days after emergence. This indicated that nitrogen in the dual band had a negative effect on fertilizer phosphorus absorption. Probably high concentrations of ammonia from the hydrolysis of urea inhibited canola roots from penetrating the fertilizer zone (Flaten and Racz, 1982).

TABLE 20

Effect of N-P placement on fertilizer P recovery (% of applied P) by canola at various growth stages.

Method of P Placement ¹	Time in days from emergence						
	20	29	36	41	55	69	98
Broadcast	15	22	58	52	65	64	68
Deep band	16	29	52	23	50	60	51
Dual band ²	10	15	20	10	44	45	47
With seed	17	19	62	52	78	81	70
Below seed	3	24	41	35	50	54	60

¹Nitrogen was added in a separate operation as broadcast application²Nitrogen and phosphorus were placed together in deep bands (10 cm)Rate of N=200 kg ha⁻¹, Rate of P=10 kg ha⁻¹

6.1.3.5 Effect of N and P placement on dry matter production (kg ha^{-1}) of flax at various growth stages

Total yields of flax for each P placement method and harvest date are shown in Table 21.

In the first 20 days after emergence, yields of flax were not significantly influenced by either P application or method of placement. However, yields on the plots that received P as preplant deep band application (single and dual bands), were lower compared to those of other treatments including the control. Low yields realized on these plots were mainly associated with poor emergence that was caused by deeper seeding than was desired as a result of seedbed disruption due to the banding operation.

Dry matter yield of the control plot was 275 kg ha^{-1} twenty days after emergence and increased to 5853 kg ha^{-1} over the subsequent 49 day period. At maturity the control plot yielded 2050 kg ha^{-1} of seed which was higher than the average yield for Manitoba and indicates good growing conditions and soil P supply.

The yield of the treatment where P was broadcast was 286 kg ha^{-1} twenty days after emergence and increased to 6697 kg ha^{-1} over the subsequent 49 day period. The yields were higher than those of the control plot, indicating the effect of P fertilization although the difference was not statistically significant. Seed yield at maturity was 2202 kg ha^{-1} , which although not significant was higher than that of the control plot. Total dry matter yield at maturity was 580 kg ha^{-1} higher than that of the control plot and was not statistically significant.

In the plots which received P as pre-plant deep band application, the yields after 20 days from emergence increased from 199 to 6940 kg ha⁻¹ over the subsequent 49 day period. Yields were not significantly different from those obtained in the treatment where P was broadcast or the control plot. Deep bands reduced plant growth at 20 days from emergence likely due to soil disruption as a result of the deep banding operation.

For the treatment which received nitrogen and phosphorus placed together in pre-plant deep bands (dual bands), yields after 20 days from emergence increased from 190 to 6663 kg ha⁻¹ over a 49 day period. The yields were generally lower than those of the treatment where P was broadcast but comparable to those of the treatment where P was deep banded alone. The low yields obtained from those plots where P, alone or in combination with N, was deep banded and soils were disturbed may in part be explained by the poor emergence and low plant density associated with these plots.

Where P was placed with the seed, the yields after 20 days from emergence increased from 300 to 7542 kg ha⁻¹ over the subsequent 49 days. Yields were higher than those obtained in the plots where P was either deep banded alone or in combination with N and also the control plot. However, although the yields were generally higher than those obtained in the plots where P was broadcast, the difference was not significant. The highest yields were observed on the plots where P was placed with the seed, probably due to early positional availability of P.

For the plots where P was placed below seed, yields increased from 282 to 7137 kg ha⁻¹ over the subsequent 49 days. Yields were generally comparable to those of the treatment where P was placed with the seed but higher than those of the plots where P was deep banded alone, deep banded in combination with N, broadcast or the control plot.

There was a reduction in total dry matter yield from 69 days after emergence to maturity in all the treatments except the control. The reason for the decline in dry matter yield was not evident but could be related to senescence. Seed yields in all the treatments at maturity were not significantly affected by P fertilization or placement methods and were fairly comparable within the limits of experimental error, which is usually high in field experiments.

TABLE 21

Effect of N and P placement on dry matter production (Kg ha⁻¹) of flax at various growth stages

Method of P placement ¹	Days from emergence								
	20	29	36	41	55	69	Maturity		
							Seed	Straw	Total
Control	275 a	469 b	867 c	1257 c	3451 c	5853 b	2050 a	4017 a	6067 a
Broadcast	286 a	683 ab	1196 abc	1485 bc	4295 abc	6697 ab	2202 a	4445 a	6647 a
Deep band	199 a	497 b	1083 bc	1294 c	3563 c	6940 ab	2085 a	3929 a	6014 a
Dual band ²	190 a	467 b	1126 bc	1376 c	3905 bc	6663 ab	2158 a	4031 a	6190 a
With seed	300 a	813 a	1558 a	2057 a	4973 a	7542 a	1950 a	4418 a	6368 a
Below seed	282 a	710 ab	1285 ab	1942 ab	4767 ab	7137 ab	2154 a	4401 a	6555 a

¹Nitrogen was added in a separate operation as a broadcast application²Nitrogen and Phosphorus were placed together in deep bandsRate of N=200 kg ha⁻¹, Rate of P=10 kg ha⁻¹

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

6.1.3.6 Effect of N and P placement on tissue P concentration (% P) of flax at various growth stages

In the first 20 days after emergence, the P concentration of the fertilized flax was very similar to that of the control except for the treatment wherein P was placed with the seed (Table 22). This indicated that emerging seedlings of flax can recover fertilizer P but root system development was not extensive enough to reach the P placed even a few centimetres away from the seed.

Tissue P concentrations ranged from 0.12 to 0.43 % between 20 and 69 days after emergence. In all the treatments, the concentrations generally increased from first harvest (20 days after emergence) to the fourth harvest (41 days after emergence) and decreased thereafter until maturity. This coincided with large increase in yield (Table 21) that occurred after day 41 and reflects a dilution effect.

At maturity, the P concentration of the seed ranged from 0.29 to 0.42 %. However, only the treatment where P was placed with the seed resulted in greater P concentration than the control and the treatments where P was deep banded alone or in combination with nitrogen. Phosphorus content of the straw was only 0.04 to 0.05 % and indicated that translocation of P from straw to seed had occurred.

TABLE 22

Effect of N and P placement on tissue P concentration (% P) of flax at various growth stages

Method of P placement ¹	Days from emergence							
	20	29	36	41	55	69	Maturity	
							Seed	Straw
Control	0.24	0.28	0.42	0.37	-	0.13	0.32 b	0.04
Broadcast	0.26	0.28	0.39	0.38	-	0.13	0.34 ab	0.05
Deep band	0.25	0.32	0.38	0.43	-	0.12	0.32 b	0.04
Dual band ²	0.23	0.28	0.35	0.35	-	0.13	0.29 b	0.04
With seed	0.35	0.28	0.37	0.39	-	0.13	0.42 a	0.05
Below seed	0.27	0.25	0.36	0.38	-	0.13	0.34 ab	0.05

¹Nitrogen was added in a separate operation as a broadcast application²Nitrogen and Phosphorus were placed together in deep bandsRate of N=200 kg ha⁻¹, Rate of P=10 kg ha⁻¹

6.1.3.7 Effect of N and P placement on P accumulation (kg ha^{-1}) of flax at various growth stages

Total P accumulation is a function of total dry matter yield and total tissue P concentration. The greatest uptake occurred, in general, in the plots where P was placed with the seed and this may be due to early positional availability of fertilizer P to the plants (Table 23). Deep bands resulted in lower uptake in early growth stages. This may be due to seedbed disruption caused by deep banding operation but is more likely due to distance of P from the seed. A significantly lower uptake was noted between harvest 29 and 41 days after emergence for the treatment where P was deep banded together with N compared to that obtained from the treatment where P was placed with the seed. Similar trends were observed in total P uptake at maturity. The low P uptake in the plots where N and P were placed in common deep bands may be due to high levels of ammonia in the bands discouraging root proliferation into the P fertilizer zone during the early stages of plant growth (Flaten and Racz, 1982).

The amount of P contained in the seed at maturity was not significantly affected by either P application or method of placement. About 80 % of total phosphorus was contained in the seed in all treatments. The amounts of P measured in the straw represented about 20 % of total P and did not differ significantly among treatments. Total P accumulation at maturity ranged from 7.72 to 10.28 kg ha^{-1} . There was little difference due to treatment; however, the treatment where P was placed in dual bands resulted in the lowest uptake and where P was placed with the seed gave the highest uptake. Phosphorus placed with

the seed resulted in significantly higher uptake compared with placement of N and P together in deep bands. Low total P on these plots was consistent with the low yields obtained (Table 21) and may be associated with poor emergence observed on the plots due to soil disturbance caused by the deep banding operation.

TABLE 23

Effect of N and P placement on P accumulation (Kg ha^{-1}) of flax at various growth stages

Method of P placement ¹	Days from emergence								
	20	29	36	41	55	69	Maturity		
							Seed	Straw	Total
Control	0.66 a	1.30 b	3.65 c	4.59 c	-	7.70 a	6.49 a	1.66 a	8.15 ab
Broadcast	0.76 a	1.90 ab	4.66 abc	5.73 abc	-	8.97 a	7.45 a	2.13 a	9.58 ab
Deep band	0.51 a	1.52 ab	4.12 bc	5.55 bc	-	8.15 a	6.56 a	1.64 a	8.20 ab
Dual band ²	0.44 a	1.31 b	3.92 c	4.80 c	-	8.64 a	6.16 a	1.56 a	7.72 b
With seed	1.05 a	2.29 a	5.77 a	8.01 a	-	9.83 a	8.23 a	2.05 a	10.28 a
Below seed	0.75 a	1.78 ab	4.62 abc	7.35 ab	-	9.45 a	7.32 a	2.06 a	9.58 ab

¹Nitrogen was added in a separate operation as a broadcast application²Nitrogen and Phosphorus were placed together in deep bandsRate of N=200 kg ha^{-1} , Rate of P=10 kg ha^{-1}

The figures in each column followed by the same letter(s) are not significantly different according to Tukey's test (P=0.05)

6.1.3.8 Effect of N and P placement on P recovery (% of applied P) by flax at various growth stages

During the first 20 days from emergence flax plants in the plots where phosphorus was placed with the seed utilized appreciable amounts of fertilizer phosphorus compared to other phosphorus placement methods (Table 24). At day 20 since emergence, apparently the plants in the plots where phosphorus was deep banded alone or in combination with nitrogen had not started recovering fertilizer phosphorus. Probably plant roots had not penetrated the bands and this may be attributed to the distance factor.

Highest phosphorus recovery by flax was observed in the plants where phosphorus was placed with the seed and this was consistent at all stages of plant growth. This results may be explained by early positional availability of phosphorus placed with the seed.

Where phosphorus was broadcast or banded below the seed, the amounts of phosphorus recovered were equivalent until after day 36 since emergence, when the amounts of phosphorus recovered by plants in the plots where phosphorus was banded below the seed exceeded those in the plants where phosphorus was broadcast.

Lowest amounts of phosphorus recovered were observed in the plants which received nitrogen and phosphorus placed in common bands. Apparently, flax plants in this plot did not start recovering fertilizer phosphorus until after 29 days since emergence. Comparatively, the amounts of phosphorus recovered by flax plants in this plot were substantially lower than those observed in the plants where phosphorus was singly banded. This difference in phosphorus recovery may be

associated with delayed penetration of plant roots into the band containing high levels of nitrogen in the form of ammonia (Flaten and Racz, 1982) at early stage of plant growth.

TABLE 24

Effect of N-P placement on fertilizer P recovery (% of applied P) by flax at various growth stages

Method of P Placement ¹	Time in days from emergence						
	20	29	36	41	55	69	98
Broadcast	1	6	10	11	-	13	14
Deep band	0	2	5	10	-	5	1
Dual band ²	0	0	3	2	-	9	0
With seed	4	10	21	34	-	21	21
Below seed	1	5	25	28	-	18	14

¹Nitrogen was added in a separate operation as broadcast application²Nitrogen and phosphorus were placed together in deep bands (10 cm)Rate of N=200 kg ha⁻¹, Rate of P=10 kg ha⁻¹

6.1.4 Summary and conclusions

Under the conditions of this experiment response of canola to applied phosphorus was limited. Generally, canola responded, as measured by yield and phosphorus uptake, to phosphorus placed with the seed and this was consistent with phosphorus recovery calculated by the difference method. Low yields and phosphorus uptake were observed where phosphorus was deep banded alone or in combination with nitrogen. This was not unexpected because other workers in Manitoba (Bailey, 1980) found that there is no significance in deep banding phosphorus at low rates. Nitrogen placed in a common band with phosphorus did not influence yields of canola.

For flax, highest yields and phosphorus uptake were obtained on the plots which received phosphorus placed with the seed and the lowest were observed on the plots where phosphorus was deep banded alone or in combination with nitrogen. Broadcast and below seed placed phosphorus resulted in intermediate yields and phosphorus uptake. Despite the fact that flax responded to phosphorus placed with the seed over the growing period until boll filling stage, this significant response was not reflected in yield at maturity. Seed yield from the control plot was comparable to yields observed on phosphorus treated plots. Apparently phosphorus was not a limiting factor to the growth of flax. Flax plants in the plot where phosphorus was placed with the seed absorbed the highest amount of phosphorus compared to other treatments. This trend in phosphorus absorption by the plants which received phosphorus placed with the seed was also reflected in phosphorus recovery calculated by the difference method. Highest amount of phosphorus recovered was

observed in the plants where phosphorus was placed with the seed and lowest amount recovered were obtained in the plants where phosphorus was deep banded alone or in combination with nitrogen. Deep banding may not be of any significance when low rates of phosphorus are applied. A comparison of treatments where phosphorus was deep banded alone or in combination with nitrogen showed that nitrogen in common bands with phosphorus did not influence yields or phosphorus uptake of flax. The study was conducted on soil which was medium in NaHCO_3 - extractable phosphorus and had extremely high nitrate-nitrogen. The high soil nitrate-nitrogen may have affected the results of this experiment since in addition, a high rate of fertilizer nitrogen (200 kg N ha^{-1}) was applied.

Chapter VII

GROWTH BENCH EXPERIMENT 2

7.1 THE EFFECT OF N AND P PLACEMENT ON DRY MATTER PRODUCTION AND P ACCUMULATION OF FLAX

7.1.1 Introduction

The field study conducted in 1985 showed that flax responded to phosphorus placed with the seed in terms of dry matter production and total phosphorus accumulation but the response was not reflected in seed yield at maturity. Also, plants in the plots where phosphorus was placed with the seed started absorbing fertilizer soon after emergence compared to other phosphorus placement methods. Broadcast, deep banded (single or dual) and below seed placed phosphorus did not significantly influence yield and phosphorus accumulation of flax. The results also showed no significant effect of nitrogen on total phosphorus accumulation and yield. Fertilizer recovery (Table 24), however, was calculated using the difference method since ^{32}P was not used. The difference method is based on a number of assumptions and therefore it is only an approximation of fertilizer phosphorus recovery. The amount of phosphorus recovered by the plants was greater where phosphorus was placed with the seed than where either phosphorus was broadcast, placed below seed or deep banded alone or in combination with nitrogen. To elucidate the results of the 1985 field experiment with flax a growth bench experiment was designed using a more accurate procedure (Isotopic method).

The growth bench experiment was set up in summer of 1986 with flax as a test crop using ^{32}P to (1) investigate the response of flax to fertilizer phosphorus with respect to distance of placement from the seed row in terms of dry matter production and phosphorus accumulation (2) determine the effect of nitrogen on yield and phosphorus absorption by flax (3) monitor fertilizer phosphorus uptake (activity of ^{32}P in counts min^{-1}) at various times of the growth period using a Geiger counter.

7.1.2 Materials and methods

The soil used was taken from the 0-15 cm depth of an Almasippi LFS near St. Claude (SE21-7-6W). It was selected because it was medium in NaHCO_3 -extractable phosphorus and low in carbonate content (Table 25).

The soil was air-dried, passed through a 2-mm sieve and mixed thoroughly prior to use. Field capacity of the soil was determined to allow controlled watering of the plants. Soil samples were prepared for laboratory chemical analysis to characterize the soil (Table 25). The containers used were large wooden boxes measuring 46 cm long by 26 cm wide and were 30 cm deep lined with plastic. The boxes were longer than desired to accomodate one row of flax, thus an acrylic plastic divider was used to reduce the box length from 46 cm to 30 cm. Twenty six kg of air dried soil was placed in the plastic lined boxes. The experiment consisted of 5 treatments, each replicated 3 times and the 15 boxes were arranged in a completely randomized design on the growth bench. Supplemental elements were added in a similar manner and at the same rates using same compounds as described previously in the first growth

bench experiment. The rates of nitrogen and phosphorus used were 100 kg N ha⁻¹ as urea (46-0-0) and 30 kg P ha⁻¹ as ³²P-labeled monoammonium phosphate. The preparation of radioactive phosphorus fertilizer solution was done using procedure described for the first growth bench experiment.

Nitrogen was added to all treatments (including the control) in bands 10 cm below and 10 cm to the side of the seed row. Phosphorus was either placed with the seed, banded 2.5 cm below and 2.5 cm to the side of the seed row or banded 10 cm below and 10 cm to the side of the seed row. The latter placement consisted of two treatments; one where nitrogen and phosphorus were banded separately (bands were separated by a 20-cm horizontal distance) and the other where nitrogen and phosphorus were placed in a common band (dual band). Placement of the fertilizers was accomplished by adding a predetermined amount of soil to the boxes to bring the level to 10 cm from the seeding level, adding distilled water to bring soil to field capacity and allowing the soil to equilibrate before nitrogen and phosphorus were banded. The bands were then covered with more soil to the level of seeding in the treatments where nitrogen and phosphorus were banded 10 cm below and 10 cm to the side of the seed row and appropriate amount of water was added to bring the top 10-cm layer to field capacity. Where phosphorus was banded 2.5 cm below and 2.5 cm to the side of the seed row, a 7.5 cm-layer of soil was added and brought to field capacity; after equilibration the bands were placed and a final 3-cm layer was added and brought to field capacity.

Flax (Linum usitatissimum L., var. Dufferin) was seeded in a single row on May 20. About 15 seeds were used in each row. The crop emerged

on May 23 and 5 days later, the plants were thinned to bring the population to 10 plants per row. The plants were watered using a similar procedure described previously for first growth bench experiment.

Temperature and humidity could not be controlled on the growth bench. The light intensity was low and ranged from 280 to 330 microeinsteins $m^{-2} s^{-1}$ at the surface of the crop canopy. Day length was set at 16 hours.

Fertilizer phosphorus uptake (activity in counts min^{-1}) was monitored using a hand held Geiger counter from May 28 to July 1. This was done by passing the window of the counter close to the row of crop and reading the counts min^{-1} on the counter scale.

At 42 days from emergence, the experiment was prematurely terminated due to rootrot infection⁵. Plants were harvested, oven-dried at 60 °C and weighed to determine dry matter production. Dry plant samples were then ground in a Wiley mill and total phosphorus and fertilizer phosphorus determined as described in the general materials and methods.

⁵ Root culture preparation and identification of rootrot fungus, courtesy of Tony Sturz, Post Doctorate Fellow, Plant Science Department.

TABLE 25

Characteristics of the soil used for growth bench experiment 2

Location	St. Claude
Soil series	Almassipi
Texture	SL
Conductivity (mmhos)	0.2
Carbonate content	Low
NaHCO ₃ -extractable P (ppm)	10.0
NO ₃ -N (ppm)	5.0
Exchangeable K	232.0
SO ₄ -S (ppm)	4.0
Organic matter content (%)	3.0
Field capacity (% of dry weight)	22.0

7.1.3 Results and Discussion

The experiment was conducted under unfavourable conditions for plant growth. Air temperatures in the greenhouse were high, ranging from 28 to 33 °C. As a result plants may have grown under conditions of heat stress and this conditions persisted throughout the growing period starting May 20 (date of emergence) to July 4 (harvest date). High humidity conditions also prevailed over the growing period.

Dry matter production was not influenced by either phosphorus fertilization or distance of phosphorus placement from the seed (Table 26). Yields ranged from 2.7 to 3.3 g in each box and this range was not statistically significant.

Phosphorus derived from fertilizer was highest where phosphorus was placed with the seed. Phosphorus derived from fertilizer was 44 % and was significantly higher than all other placements. Phosphorus derived from fertilizer P sidebanded (2.5 cm x 2.5 cm) from the seed row was 17 % which was significantly higher than the two deep band treatments but significantly lower than from seed placed phosphorus. Deep sidebanding (10 cm x 10 cm) of phosphorus resulted in low recoveries of fertilizer phosphorus, and there was virtually no difference in recovery of phosphorus comparing single or dual band application.

A hand held Geiger counter was used to monitor fertilizer phosphorus accumulation at intervals after crop emergence. The counter window was passed over the vegetation, just clearing the top of it. Variations in height above the plants and in the speed of scaling undoubtedly occurred. The ^{32}P activity in the plants is plotted in Figure 4.

Fertilizer phosphorus uptake was detected within 6 days from emergence where phosphorus was placed with the seed. Uptake was not detected on other placements for at least 14 days after emergence. At 14 days since emergence, phosphorus uptake from sidebands close to the seed was detected, and at 18 days since emergence uptake from deep sidebands was detected. After initial uptake started, it continued at a rapid rate where phosphorus was placed with the seed but at a lower rate where phosphorus was sidebanded close to the seed and least where phosphorus was deep sidebanded (10 cm x 10 cm). This measurement indicates that the increased proportion of phosphorus derived from fertilizer resulting from seed placed phosphorus was due, in part, to early uptake of fertilizer phosphorus. Total fertilizer phosphorus (Table 26) in flax where phosphorus was placed with the seed was substantially higher than that observed in the plants where phosphorus was placed away from the seed (either close or away from the seed). However, the amount of phosphorus taken up by plants did not differ significantly among the treatments where phosphorus was placed away from the seed. Similarly, total fertilizer phosphorus in the plants where nitrogen and phosphorus were banded (10 cm below and 10 cm to the side) either separately or together, did not differ substantially. Low total fertilizer phosphorus taken up by plants in the treatment where phosphorus was banded away from the seed compared to where phosphorus was placed with the seed may be attributed to delayed uptake due to distance from the seed.

The data for total soil phosphorus (Table 26) indicated no statistical significance with respect to distance of phosphorus placement from the seed. Highest amount of total soil phosphorus

occurred in the plants where no fertilizer phosphorus was applied and where nitrogen and phosphorus were deep banded together (10 cm x 10 cm) away from the seed; and the lowest amount was observed in the plants where phosphorus was placed with the seed. Though not explicitly, the results seem to indicate an inverse relationship between total fertilizer phosphorus and total soil phosphorus taken up by flax.

Generally total phosphorus taken up was not affected by the treatments. Flax plants absorbed soil phosphorus to compensate for low uptake of fertilizer phosphorus. This indicates that soil phosphorus levels were generally satisfactory for flax.

TABLE 26

The effect of N-P placement on dry matter production and P accumulation of flax

Phosphorus placement	Dry matter yield (mg/box)	Pdff (%)	Fertilizer P uptake (mg/box)	Soil P uptake (mg/box)	Total P uptake (mg/box)
Control	2.9 a	-	-	12.1 a	12.1 a
With seed	3.3 a	44 a	5.2 a	6.6 a	11.7 a
2.5 cm below-2.5 cm beside seed	2.7 a	17 b	1.6 b	7.8 a	9.4 a
10 cm below-10 cm beside seed (Separate)	3.0 a	7 c	0.8 b	9.9 a	10.7 a
10 cm below-10 cm beside seed (Dual)	3.3 a	9 c	1.2 b	11.8 a	13.0 a

Figures in the same column followed by the same letter(s) are not significantly different according to Tukey's w test (P=0.05)

All treatments received nitrogen in the form of urea (46-0-0) banded 10 cm below and 10 cm to the side of the seed row at the rate of 100 kg N ha⁻¹
Phosphorus was applied as ³²P-labeled monoammonium phosphate (11-51-0)

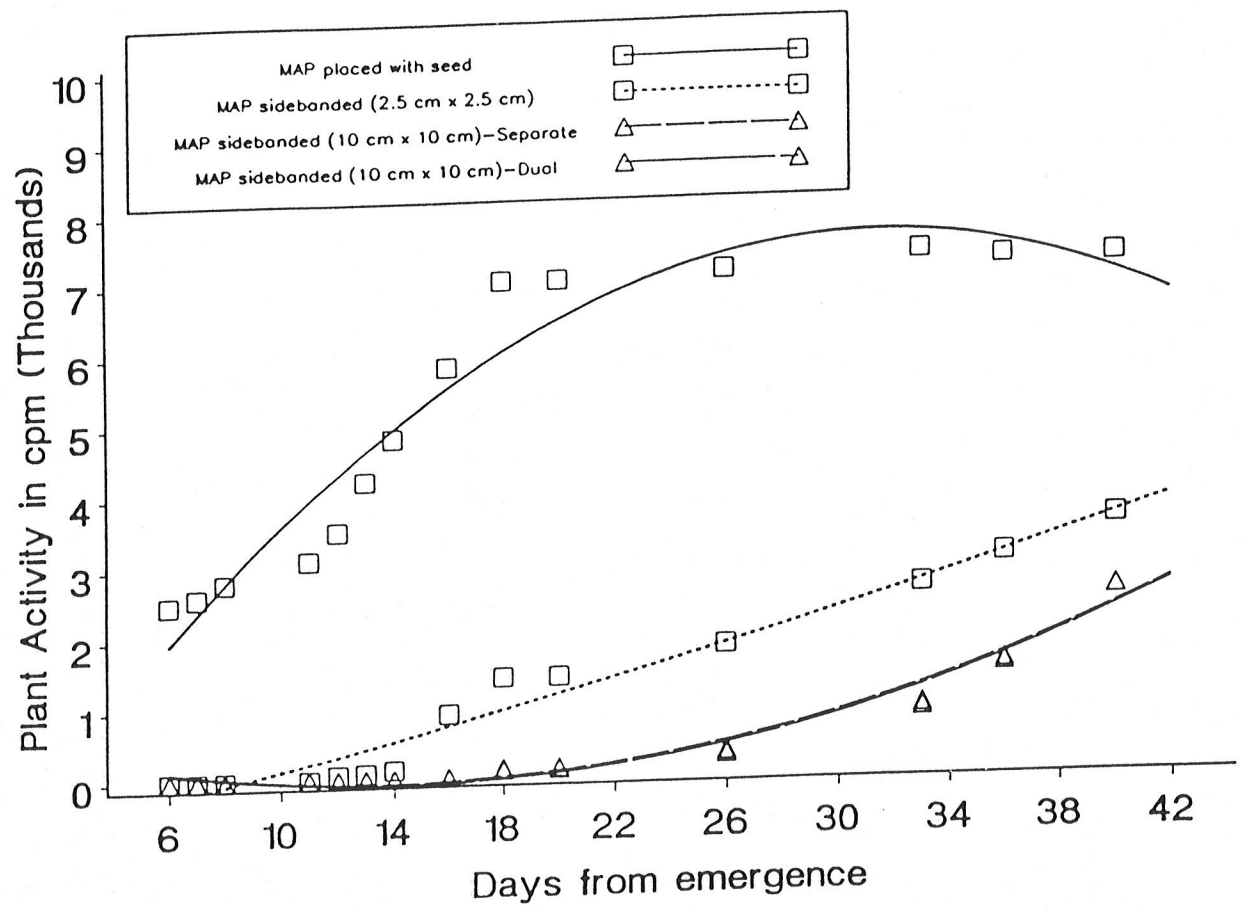


Figure 5: Effect of N-P placement on ³²P activity (cpm) in plants at various times of growth

7.1.4 Summary and conclusions

Under the conditions of this experiment placement of phosphorus with the seed resulted in early fertilizer phosphorus utilization compared to placement away from the seed. Hence at the time of harvest (42 days from emergence) the amount of fertilizer phosphorus absorbed by flax was significantly higher where phosphorus was placed with the seed than where phosphorus was placed away from the seed. However, plants in the treatments where phosphorus was banded away from the seed compensated for the low fertilizer phosphorus uptake by utilizing soil phosphorus. This nullified any differences in terms of dry matter production and total phosphorus in the plants. At the stage of growth when plants were harvested, there was no significant advantage associated with banding nitrogen and phosphorus in a common band away from the seed.

Data obtained over the growing period using Geiger counter showed that placement of phosphorus with the seed resulted in early fertilizer phosphorus utilization by flax; and placement of phosphorus away from the seed resulted in a delay of fertilizer phosphorus utilization of about 14 to 18 days.

The results of the experiment were affected by unfavourable growing period temperatures and humidity which may have resulted in heat stress. Soil used contained 10 ppm of NaHCO_3 -extractable phosphorus and under the conditions of growth, plants utilized this amount of phosphorus as well as applied phosphorus.

Chapter VIII

SUMMARY AND CONCLUSIONS

The study of the influence of N-P placement combinations on yield and phosphorus uptake consisted of two field experiments and two growth bench experiments. Soils used in both field and growth bench experiments were medium in NaHCO_3 -extractable phosphorus. In the first field experiment, plant sampling for yield and phosphorus uptake determination was done at flowering stage and maturity. The first growth bench experiment was harvested at flowering stage to determine dry matter production and phosphorus accumulation. The second field experiment involved a series of harvests at different stages of growth of canola and flax for total yield and phosphorus accumulation. Results from the first field experiment showed no significant response to applied phosphorus for canola and flax. Nitrogen and phosphorus combinations did not substantially influence yield and phosphorus uptake. However, protein and oil content of canola exhibited an inverse relationship; which may be attributed to a dilution effect due to large seed size caused by high absorption of nitrogen. There was, however, no treatment effect on both protein and oil content. Protein and oil content of flax were virtually not influenced by the various N-P placement combinations.

The first growth bench experiment with canola showed a general response to phosphorus fertilization in terms of dry matter production and phosphorus accumulation. However, dry matter production and total

phosphorus absorption did not differ significantly among the various N-P placement combinations. Highest dry matter production was realized in the treatment where urea and phosphorus were banded separately close to the seed row (2.5 cm below x 2.5 cm to the side). This was consistent with the data (^{32}P activity in plants) obtained using a hand held Geiger counter, which showed high ^{32}P intensity over other N-P placement combinations, starting soon after emergence. Among dual band placements, lowest dry matter production, fertilizer and total phosphorus accumulation was observed where urea and phosphorus were banded 2.5 cm directly below the seed row. A comparison of banded phosphorus (2.5 cm x 2.5 cm) with phosphorus mixed with the soil showed that dry matter production was not affected by either method of placement; however, canola accumulated significantly greater amounts of fertilizer phosphorus from the band than from a mixed application. Lowest fertilizer phosphorus accumulation occurred where phosphorus was mixed with the soil and this was not unexpected since the soil had high pH of 8.4 and was high in carbonate content. There was no significant advantage associated with either source of nitrogen (urea or ammonium nitrate) or urea placed in a common band with phosphorus (2.5 cm below x 2.5 cm to the side).

The second field experiment results for canola showed no significant differences in terms of dry matter production for phosphorus treated plots in the vegetative to pod filling stage. Highest dry matter production, however, was observed in the plots which received phosphorus placed with the seed. Lowest yields were obtained where phosphorus was deep banded alone or in combination with nitrogen. At maturity,

substantially higher yield was obtained from the plots where phosphorus was placed with the seed compared to the treatments where phosphorus was deep banded together with nitrogen or placed 2.5 cm directly below the seed. In general seed yields obtained from all treatments including the control were high and above average canola yield for Manitoba and this was likely due to medium NaHCO_3 -extractable phosphorus and extremely high levels of nitrate-nitrogen. There was no yield advantage attributed to nitrogen in a common deep band with phosphorus. Lower yields were observed where phosphorus was deep banded and this was related to poor crop emergence caused by deep banding operation. Canola tissue phosphorus concentrations from early vegetative samples to pod filling stage did not differ significantly among treatments; however, the general trend indicated a decline in tissue phosphorus concentration with time and this was attributed to the dilution effect caused by increased dry matter production. Total phosphorus accumulation exhibited similar trends observed in dry matter yield production during early vegetative stage and reproductive stages, and seed yield at maturity. Highest seed yield and total phosphorus accumulation was observed in the plants which received phosphorus placed with the seed; however, it was not significant compared to other P placement methods. Nitrogen deep banded together with phosphorus had no significant influence on total phosphorus accumulation. Fertilizer phosphorus calculated by the difference method also showed that phosphorus placed with the seed resulted in highest recovery. The superiority of phosphorus placed with the seed compared to other placement methods may be associated with early positional availability of the element to the plants.

Although dry matter yield of flax plants increased from the early stage of plant growth to the filling stage when phosphorus was placed with the seed, the seed yield at maturity was not increased. Significantly lower dry matter production was obtained where phosphorus was deep banded alone or in combination with nitrogen compared to where phosphorus was placed with the seed. Final yield data showed no significant placement effect and this may be due to the low phosphorus requirement of flax or high levels of phosphorus in the plants may have caused imbalance of micronutrient elements. Also, previous research work in Manitoba has shown that flax does not respond to added phosphorus (Soper and Racz, 1963; Racz, 1969; Bailey, 1979). Similarly, tissue phosphorus concentrations were not influenced by N-P placement combinations both in vegetative stages and at maturity. Trends in phosphorus accumulation were consistent with those observed in the yield data. Highest fertilizer phosphorus recovery was obtained in the treatment where phosphorus was placed with the seed. Flax in general was not responsive to the various N-P placement combinations.

The second growth bench experiment in the greenhouse with flax showed that flax started using phosphorus placed with the seed soon after emergence. But the treatments where phosphorus was banded away from the seed (close or deep) showed a delay in phosphorus uptake with distance from the seed row. The plants in the treatment where phosphorus was placed with the seed derived substantially high amounts of phosphorus from fertilizer compared to those where phosphorus was banded away from the seed (close or deep), however, total phosphorus accumulation was not affected by treatments including the control. This indicates that soil

phosphorus concentration was adequate enough for flax and the plants which had no access to fertilizer phosphorus compensated by utilizing soil phosphorus. Dry matter production was also not influenced by treatments. Nitrogen deep banded with phosphorus had no substantial effect on dry matter production and fertilizer phosphorus accumulation.

Field crop recommendations for Manitoba⁶ indicate that phosphorus for flax can be applied at the rates of up to 20 kg P ha⁻¹ provided that the phosphorus is placed directly below or sidebanded close to the seed, but not placed with the seed. Results from the studies conducted generally support this recommendation, however, phosphorus placed with the seed did provide increased growth and plant vigor at early growth stages. Similarly, recommendations for P fertilization of canola are; to apply up to 20 kg P ha⁻¹ sidebanded close to the seed or up to 10 kg P ha⁻¹ with the seed. In these studies best results were obtained with P placed with the seed, and in general results support the Provincial recommendations.

⁶ Field Crop Recommendations for Manitoba, 1985

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