THE UNIVERSITY OF MANITOBA

Phosphorus as a Limiting Nutrient for Maximum Production of Wheat in Manitoba

By

William Kamugisha Modestus

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ABSTRACT

The influence of P additions and various methods of P application on the maximum yield of wheat was studied in the field, growth chamber and lysimeter experiments.

The influence of soil moisture regimes and P additions on dry matter yield and phosphorus derived from fertilizer (Pdff) was investigated in a growth chamber experiment. The effect of P additions and water supply on water use efficiency was also investigated in the same experiment. The low soil moisture regime reduced yields and Pdff by about twofold but had little effect on the shoot P concentrations. The Pdff increased with increase in P additions in both high and low soil moisture regimes, but a similar increase in dry matter yields was observed only in the high moisture treatment. Additions of P increased water use efficiency significantly but the quantity of water supplied to the plants did not affect the water use efficiency.

Results from the field showed that maximum yield of wheat could be obtained without adding P in soil with medium to high levels of $NaHCo_3$ extractable P. However, in soils low in $NaHCO_3$ extractable P, a considerable amount of broadcast P is required to obtain the maximum yield. The amount of broadcast P required to obtain maximum yields could be reduced to one-half by banding an extra small amount of P with the seed. Results from the soil low in available P, both in the field and growth chamber studies indicated a reduction of grain [Cu] to below the critical level at the highest rates of P. In the growth chamber experiment, grain yield responded to low and medium rates of P without

Cu added. A further grain yield increase at higher rates of P only occurred when Cu was added to soil.

The effect of depth of placement of P on yields and uptakes was studied in the growth chamber, lysimeters and field experiments. The results from the field and lysimeter experiments indicated that 0-7.5 cm and 0-15 cm depths of P incorporation were equally effective in terms of P availability to the plants. From the lysimeters the shallow placement (up to 15 cm deep) was better than the 15-30 cm or 0-30 cm depths of P placement. Under controlled environment in the growth chamber however, the 0-15 cm and 15-30 cm depths of P placement were equally effective in terms of yield response to P.

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Chapter 1

INTRODUCTION

It is a common practice for farmers to use phosphate in wheat production as this element is deficient in most soils and without adequate supply maximum yields can not be achieved. Yield responses to P have been variable from year to year and from one place to another. The quantity and methods of P application are partly responsible for such variations, as P is less mobile in soil and is readily fixed by soil constituents. Environmental factors may also influence the yield responses to P. Soil moisture in particular plays an important role in influencing yields. Low soil moisture during the growing period may result in low yields by affecting the supply of P to the plants. Low soil moisture may also influence yields by affecting the plant itself morphologically and physiologically (Peters, 1957; Salim et al., 1965). Agronomical practices such as deep incorporation of P which ensures that P is placed into moisture where it is available when moisture is limiting at shallow depths have attracted attention of many researchers for a long time. Results obtained with this method so far are variable. Some researchers have recorded increases in yield due to this method (Jamison and Thorntone, 1960; McEwen and Johnston, 1978) while others reported that deep incorporation was inferior to shallow application of P (Phillips and Norman, 1967). More work is still required to evaluate the benefit of this technique.

Growth chamber, lysimeter and field experiments were undertaken to determine ways under which maximum grain yield could be attained from P fertilization. The detailed objectives of each study are given in the introductory remarks of each study.

Chapter 2

LITERATURE REVIEW

A. Effect of P Deficiency in Wheat

A primary effect of phosphate on autotrophic growth is the provision of chemical energy produced in the chloroplast (Walker, 1980). As numerous metabolic processes directly or indirectly depend on this energy supply, inadequate phosphate nutrition may affect various processes including protein synthesis and synthesis of nucleic acids. Phosphate deficient plants have retarded growth and low shoot/root ratios. In cereals, tillering is reduced (Mengel and Kirby, 1982). The net result of the above is that maximum yield can not be attained unless the deficiency is corrected. In seed, phytin, an organic phosphate substance serves as storage form of phosphate in seed and, on germination, phosphorus from this acid, or its salts becomes available for phosphorylation reactions in the metabolism of the seedling (Arnon, 1953).

B. Effect of Soil Moisture Content on P-Uptake

Environmental factors such as temperature and/or soil moisture can influence phosphorus uptake by wheat and other crops. This can explain in part, the variations in crop response to phosphorus fertilizer noted from year to year. Furguson (1964) analyzed data for wheat grown on the Canadian Prairies from 1936 to 1962 and noted that less than 25% of the variation in crop response could be accounted for by measurements of 'available phosphorus' by soil analysis. The prediction of crop response to fertilizer phosphorus improved by inclusion of rainfall data. Similar observations were made by Mack (1965), Vos et al. (1970), Nutall et al. (1979), Modestus et al. (1980).

Soil moisture can influence the uptake of phosphorus by either affecting the supply of phosphorus to the plant (Olsen et al., 1961; Cho et al., 1970; Hira and Singh, 1970), and/or by affecting the plant itself for example, by influencing root morphology and physiology (Peters, 1957; Racz et al., 1964; Salim et al., 1965).

Olsen et al. (1961) studied phosphorus uptake by corn at various soil moisture contents. Phosphorus uptake was found to be linearly related to the volumetric water content. They concluded that diffusion of phosphorus particularly when reduced by low soil water contents, was a significant limiting factor in plant phosphorus uptake. Some work conducted by Boatwright et al. (1964) showed that wheat plants do not absorb fertilizer phosphorus from dry soil. Hira and Singh (1977) also reported that phosphorus diffusion was a function of soil water content apart from bulk density.

Soil water content modifies root distribution in a major way. Generally, root growth in dry soil is restricted. Racz et al. (1964) studied the effect of water tension on root distribution of wheat grown in pots and found a greater root development at all depths for the plants grown under low water tension. However, a greater percentage of roots of the highly stressed plants was found in the 0 to 5 cm layer. Peters (1957) noted a one half reduction in growth rate of maize roots as the soil suction increased from a low value to 8 bars. The degree of moisture stress seems to be a very important factor in determining the number and distribution of roots in the profile. Under conditions when the surface soil is not disturbed and it is protected from strong evaporation for example by mulch, the roots may develop right up to the soil surface, (Pers. Observ.). Also, frequent light showers of rain or frequent irrigation which keep the soil surface moist encourage shallow rooting (Hurd, 1964). Hurd (1968) studied the growth of roots of spring wheat at high and low moisture levels. He found that roots of "Thatcher" penetrated the soil more quickly in relatively dry soil (low moisture level) than in wet soil. When the soil dried out in the surface layers, root growth by "Thatcher" increased in the moist layer just below.

Since most of the soil-available phosphorus is present in the surface horizon and since fertilizer P is often placed into surface layers of soil, a marked reduction in root growth and distribution in such layers due to drought would severely limit phosphorus uptake from soil and fertilizer.

C. Effect of Amount of P and Placement Method on the Availability of Fertilizer Phosphorus

The efficiency of P-fertilizer can only be realized when right amounts of fertilizer P and proper method of application is employed. The value of a soil nutrient to a plant depends on its accessibility to the roots which is consequently related to the mobility of the nutrients in the soil. Mobile nutrients, such as nitrogen, are absorbed from the total soil volume containing the roots and relatively immobile nutrients, such as phosphorus, likely from a thin layer of soil around each root. Lewis and Quick (1967) reported that for wheat (Triticum spp), the zone of phosphate depletion around a single root extended only

1 mm from the surface. Thus, placement of the right amount of fertilizer in the soil in a position such that plants have a ready access to it is very important.

1. Phosphorus Banded with the Seed vs. Surface Application and Incorporation

It is well documented that banding phosphorus with the seed increases the efficiency of P-uptake by the crops (Racz, 1980; Bullen et al., 1983). Placement of phosphorus in bands minimizes the contact between soil and phosphorus fertilizer. This decreases the rate of fixation and aids in maintaining a high concentration of phosphorus in the vicinity of plant roots. In contrast, mixing the phosphorus with soil exposes the phosphorus to more soil and more fixation resulting in lower phosphorus concentration than that achieved in bands. Racz (1980) in Manitoba, reported that banding of phosphorus fertilizer with the seed was one of the most efficient means of P-application when the amounts applied were not injurious.

2. Phosphorus Banded Near the Seed

When higher levels of fertilizer P are used with the idea of increasing yield, banding of all fertilizer with the seed is not desired as this results in seed and seedling injury (Nyborg and Henning, 1969; Racz, 1980). Other methods of P application are usually preferred. This includes surface application and incorporation and banding P fertilizer some distance to the side of the seed, below the seed or to the side and below the seed. Cereals such as wheat and barley can tolerate relatively high rates of P drilled with the seed. For wheat and barley as much as 44 kg P/ha could be placed with the seed without causing seed or seedling injury (Racz, 1980). However, germination and emergence of some crops are reduced when large amounts of P fertilizer are applied with the seed. The same author found that for crops like peas, sunflowers and rape seed, application of up to 9 kg P/ha with the seed enhanced yield, but with rates over 15 kgP/ha yields were reduced due to seedling injury. Sherrel et al. (1964) reported that fertilizer P absorption by oats was greater from placement of P with the seed than from those to the side at all stages of growth when low rates were used. However, at high rates of P placed up to 5 cm below the seed was superior to P with the seed.

Sadler (1969) studied the effect of placement of phosphorus away from the seed on growth and uptake of soil and fertilizer P by flax. Flax responded significantly to phosphorus placed below the seed as opposed to side banding. It was observed that to obtain the same yield it was necessary to place P-fertilizer no more than 1.5 cm to the side as compared to 1.5 to 3 cm below the seed. Studies with soybean showed phosphorus banded 5 cm below and 5 cm away from the seed was less effective compared to 2.5 cm below or away from the seed (Bullen et al., 1983).

3. Deep Banding of Fertilizer P

Deep banding of P method would be particularly important during the dry growing seasons where plant roots have to go deep down to draw water for their use (Hurd, 1968). This would mean that more roots will proliferate in the subsoil in response to water. Even if some roots remained in the top soil, absorption of P by these roots might be severely limited by low soil moisture content of the surface soil. The effect of low soil moisture on the absorption of P by corn and wheat was observed by Olsen et al. (1961) and Boatwright et al. (1964) respectively. Thus the absorption of broadcast phosphorus from or P in shallow bands with or beside the seed, may be reduced compared to deep banded phosphorus. Jamison and Thorntone (1960) working with corn and alfalfa found subsoiling and fertilization with triple super phosphate in the subsoiler clefts gave significant yield increases. However, Larson et al. (1960) observed that subsoiling to the depth of 40 and 60 cm in Iowa soils, together with fertilization at these depths, were not as effective as fertilizer ploughed under in the case of corn. Moore et al. (1968) also found that drilling P fertilizer to a depth of 7.6 to 10.2 cm resulted in lower dry matter yields and lower percentages of phosphorus as compared with surface application on two Nebraska sub-irrigated meadows. These results are variable and may be due in part, to differences in root morphology of the crop under consideration and to variable environmental conditions. Environmental conditions can influence the availability of fertilizer P placed at the shallow or deeper depths (discussed under section B).

The influence of root morphology on the uptake of fertilizer P was studied by Page and Gerwitz (1969) with lettuce and carrots. They examined crop uptake of labelled phosphates applied at different soil depths, and found that lettuce took up phosphate mainly from the upper soil layer (0 to 8 cm), whereas carrots absorbed an appreciable proportion from the 30 to 40 cm depth.

4. P Deep-Banded With Nitrogen

Studies conducted in many areas over a number of years indicate that N and P banded together had a greater effect on yield than N and P banded separately (Miller and Vij, 1962, Cole et al., 1963). Studies conducted in Manitoba and other areas of the prairies also indicate that efficiency of banded phosphorus is greater when banded with nitrogen fertilizer in the form of ammonium in intimate contact (Racz, 1980). Racz (1980) also reported that preplant deep banding of phosphorus with nitrogen at spacing of about 30 cm in Montana was superior to phosphorus placed with the seed and nitrogen deep banded before seeding.

The ammonium ion effect in increasing fertilizer phosphorus uptake has also been studied. Rennie and Soper (1958) found that ammonium salts had a positive influence on phosphorus absorption by wheat but KNO_3 and K_2SO_4 had no effect. Olson and Drier (1956) also found that ammonium compounds created a much larger effect than nitrate compounds particularly at early growth stages.

The effect of ammonium ion is thought to be partly to the enhancement of root growth in the fertilizer band. Root growth within the phosphorus fertilizer band was found to be enhanced more by phosphorus plus nitrogen application than by phosphorus only (Duncun and Ohlrogge, 1958; Miller and Vij, 1962).

There is also some evidence which that suggests that nitrogen affects the ability of the plant root to absorb phosphorus. Cole et al. (1963) and Thien and McFee (1970) using nutrient solutions found nitrogen pretreatment significantly increased phosphorus absorption and translocation rates in corn.

The concept of ammonium fertilizer lowering pH of the soil-root interphase was also proposed by Miller et al. (1970) and Riley and Barber (1971). They showed that the increased availability of phosphorus from soil with ammonium was due mainly to the decreases in pH of the root-soil interface.

D. Phosphorus and Micronutrient Interactions

Heavy application of P-fertilizer has resulted in deficiency of Zn in beans (Brown and Brown, 1968; Paulsen and Rotini, 1968) and Cu in wheat (Racz and Haluschak, 1974). Although there is some evidence (Bingham, 1963; Chaudhry et al. 1977) which indicates beneficial effects of P fertilization on micronutrients uptake (particularly Zn), it is generally agreed that high levels of P usually result in P-induced Zn and Cu deficiencies. The actual mechanism is not clearly understood. Some evidence indicates that P induced Zn or Cu deficiency is a soil factor (Bingham, 1963; Takkar et al., 1975) whereby Zn or Cu is precipitated by phosphate into unavailable forms. There is however, a general feeling that P-induced Zn or Cu deficiencies are a plant factor, and that the interaction is physiological (Brown and Brown, 1968; Paulsen and Rotimi, 1968; Racz and Haluschak, 1974; Wallace et al., 1978) whereby Zn or Cu is precipitated or inactivated by P within the plant. Solubility studies of Zn in P-treated soils (Thorne, 1957; Bingham and Garber, 1960) also do not support the notion that Zn is made unavailable by precipitation with P in the soil. Recent studies by McKenzie (1980) showed that Zn uptake by blackbeans was not affected by adding large amounts of P although plant Zn concentrations were decreased. The decrease in Zn concentrations was associated with dilution of Zn in the plant due to increased yield as the result of P additions. Dilution effect may also explain the decrease in concentration of copper and other elements when large amounts of P are added to soil to increase yields.

There are incidences where P treatments enhanced symptoms of Zn-deficiency without any reduction in Zn contents of plant tops (Batti et al., 1970; Loneragan et al., 1979). A recent study by Loneragan et al. (1982) on phosphorus accumulation and toxicity in leaves in relation to Zn supply suggested that Zn interferes with P metabolism enhancing the amounts of P absorbed by roots and translocated to the tops under conditions of high P supply. They found phosphorus accumulates to the toxic levels in leaves inducing or accentuating symptoms resembling Zn-deficiency. This effect might explain previous observations of Zn-deficiency symptoms occurring when the tissue Zn contents were normal. Studies by McKenzie (1980) and McKenzie and Soper (1983) on Zinc x phosphorus interaction on P and Zn uptake by blackbeans indicated that phosphorus uptake was regulated by the plant when sufficient Zn was present but was not regulated at low plant Zn levels. With very low levels of Zn, there were very high levels of P. The authors noted that black bean Zn uptake was not affected by phosphorus concentration as long as Zn levels remained sufficiently high. Haluschak (1971) found a very small negative effect of high P on Cu uptake by wheat and flax. Earlier studies by Bingham (1963) showed that high rates of P decreased Cu contents in citrus but not in beans, corn or tomatoes.

E. Diagnostic Techniques for Cu, Zn and P Status in Soils and Plants

Two basic methods of establishing the status of nutrients in the soil and plants are soil analysis and tissue analysis. The nutrient status in the soil or plant tissue is often expressed in concentration ranges such as deficient, low, adequate, high and toxic. Sometimes critical levels are used. A plant nutrient critical level has been defined in several ways. Jones (1972) and Munson et al. (1973) defined it as the plant nutrient concentration when yield is 5-15% below the maximum.

The critical level of a plant nutrient in the soil was defined as the level of nutrient in the soil that separated a deficient soil from a non-deficient soil (Brown et al., 1971; Matt, 1972).

Viet and Lindsay (1973) noted that micronutrient determination has many difficulties arising primarily because of low concentrations in the soils, and interaction with other micronutrients and macronutrients. Some success has been reported with soil testing (McGregor, 1972; Lindsay and Norvell, 1978). Lindsay and Norvell (1978) suggested a critical level of 0.2 mg DTPA extractable Cu/g soil on mineral soil, however, this recommendation was not based upon yield response data. McGregor (1972) investigated soil extractants for Cu to determine which was most reliable for Manitoba mineral soils. He found that the amount of Cu by 0.01 M Na_2DP (Na_2EDDHA); and 1.0 M NH_4oAC buffered at pH 7.0 correlated well with Cu concentration and uptake by flax, with r^2 values of 0.75 and 0.93 respectively. A soil critical level of 1.3 ppm Na_2EDDHA extractable Cu was suggested.

Extracting with a solution containing EDTA and ammonium carbonate buffered at pH 8.6 has been found to be a reliable soil test for Zn (Whitney, 1975). Lindsay and Norvell (1978) found that a DTPA soil extraction was also a good indicator of the Zn status in the neutral to alkaline soils. A critical level of 0.8 mg DTPA extracted Zn/g soil was suggested. However, McAndrew (1979) recorded no grain yield response to Zn fertilization in cereals and oilseed crops grown on soil containing as little as 0.8 DTPA extractable Zn/g soil although Zn shoot concentrations often increased. This led the author to conclude that the critical level for cereals and oilseeds is probably lower than 0.8 mg Zn/g soil suggested in the literature.

Soil analysis for P and other macronutrients is generally more reliable than soil analysis for micronutrients simply because they are always present in the soil in relatively higher concentrations. There are several methods of P extraction as outlined by Thomas and Peaslee (1973); the choice of a particular procedure being determined by soil properties. The two most widely used soil extractants for P analysis in Western Canada are the $NaHCO_3$ and acid-fluoride techniques (Leitch et al., 1980). The acid-fluoride technique is generally considered the best index of P availability for soils with low to medium C.E.C. that have been moderately to highly weathered, whereas $NaHCO_3$ extraction is often considered to be more effective on those soils having neutral to alkaline reaction, high C.E.C. and presence of free lime. In some cases, little difference has been noticed between these two methods in predicting P response on a wide range of soils (Robertson, 1962; John et al., 1967). The values in Table 1 gives P categories used by the provincial soil testing laboratories in Manitoba and Saskatchewan using $NaHCO_3$ extracting procedure.

Table 1: Categories of $NaHCO_3$ Extractable Soil P (kg/ha) from the Provincial Soil Testing Laboratories in Manitoba and Saskatchewan

Province	CATEGORY				
	Very Low	Low	Medium	High	Very High
		kg/ha P	in	0-15 cm	Depth
Saskatchewan	0 - 11	12 - 17	18 - 22	23 - 24	> 34
Manitoba	0 - 11	12 - 19	20 - 28	29 - 40	> 40

Source: Leitch et al. (1980)

In plant tissue analysis, plant material is usually ashed or digested leaving only the inorganic constituents behind (Jones, 1972). Critical levels and concentration ranges depend upon the stage of growth and part of the plant sampled (Jones, 1967). Melsted et al. (1969) reported that the Cu critical level for wheat sampled as a whole above ground plant at boot stage was 5 ppm. Gupta et al. (1970) considered that 3.3 ppm Cu at the same stage was optimum. Copper concentrations in plant shoots were considered low when they ranged from 2.3 - 3.7 ppm for barley, 1.7 - 3.5 ppm for oats, 3.0 - 4.9 ppm for wheat, 2.4 - 3.5 ppm for flax and 1.7 - 2.7 ppm for rapeseed at 45, 49, 52, 43 and 43 days after seeding respectively (McAndrew, 1979). Other researchers have used grain Cu-content to assess Cu-nutritional status in cereals. Russ (1958) considered 2.5 - 3.0 ppm to be the critical Cu-content for oats.

A zinc concentration of 15 ppm for wheat, sampled at the boot stage was reported as a critical level (Melsted et al., 1969). The same value (15 ppm Zn) was reported by Ward et al. (1973) for wheat shoots at heading stage. Akinyende (1978) suggested a critical level of 12.5 ppm Zn for barley at heading stage.

The P contents of P-deficient plants are generally low with about 0.15% or less in dry matter. Cereals adequately supplied with phosphate have P contents of approximately 0.3% to 0.4% P in dry matter at boot stage to heading stage (McAndrew, 1979; Mengel and Kirby, 1982). Melsted et al. (1969), after compiling data from many years and different soils reported a critical value of 0.30% P for wheat plant at the boot stage. Ward et al. (1973) indicated that P-deficiency in barley, oats and wheat can be expected if the concentration of P at the stage when the head emerges from the boot is less than 0.20%. Mengel and Kirby (1982) reported that a value of 0.1% to 0.15% in dry matter is common in mature cereal straw; whereas in seed and grain P content is in the range of 0.4 to 0.5% P.

F. Harvest Index

The harvest index describes the amounts of photosynthate which ends up in grain formation. It is a ratio of grain yield to biological yield (Donald, 1962). More often it is expressed in percentages (van Dobben et al., 1962; Vogel et al., 1963). Ideally, biological yield would include roots, but since roots are particularly difficult to recover from the soil, the biological yield in this sense refers to the above ground portion.

A high harvest index in a crop can be achieved if there are many ears per unit area, each ear with a high yield of grain and relatively short, light stems and few, short narrow leaves per stem (Donald and

Hamblin, 1976). Analysis by Singh and Stoskopf (1971) showed that stems contributed 32% of the biological yield or 56% to the vegetative parts in cereals. Usually biological yield increases with increasing population density to a maximum value determined by some factor(s) of the environment and at higher density tend to remain constant, provided no other factors are limiting. Grain yield increases to a maximum value but declines as the density is further increased (Donald and Hamblin, 1976). The decline in grain yield as the plant population density is increased probably is due to low light profile within the crop canopy (Fisher and Wilson, 1975). The harvest index for wheat seems to be very variable. A harvest index as low as 27% has been reported (Vogel et al., 1963) and a harvest index as high as 50% has also been reported (Donald, 1963).

The environment has a strong influence on the value of the harvest index. The environmental factors of great significance in cereal production are water availability, population density and nutrient supply, particularly nitrogen (Donald and Hamblin, 1976). High nitrogen supply for example, is known to depress the harvest index by promoting vegetative growth at the expense of grain production. McNeal et al. (1971) reported data for spring wheat in Montana where the harvest index fell from 43% to 39% with a high nitrogen application. A good supply of phosphorus, however, tends to counteract the bad effect of nitrogen. Copper deficiency in cereals and other crops has been found to depress harvest index by affecting grain formation (Scharrer and Schaumloffel, 1960; Brown and Clark, 1977). These observations were in agreement with those of Graves and Stucliffel (1974) who found that the initiation and development of flowers were delayed by lack of copper in Chrysanthemum morifolium. McAndrew (1979) found that the floral parts of rape seed plants were vertically compressed and malformed as the result of copper deficiency. A recent growth chamber study* on wheat grown on Cu-deficient soils showed no grain yield formation when no copper fertilizer was added. However, vegetative growth was little affected. The above examples illustrate the importance of copper for the reproductive phase apart from other functions in the plant which obviously will affect the harvest index.

Available water has an influence on nutrient availability thereby influencing the plant population density which consequently affect ears per unit area and weight of grain per ear (Donald and Hamblin, 1976).

G. Water Use Efficiency

Water use efficiency is defined as the amount of water (transpiration, plant growth, evaporation) required to produce a unit of dry matter material (Donahue et al., 1977). Viets (1962) defined water use efficiency as the amount of dry matter produced per unit water evapotranspired.

Water use efficiency increases as the water used per unit production decreases. There are many factors which influence water use efficiency. Soil fertility in particular, has been found to have a strong influence on water use efficiency (Viets, 1962; Bauer et al., 1966; Krogman, 1967). Improved efficiency of water use in fertilized

* Pers. Communication with J. Kamwaga-Dept. Soil Sci. (Univ of Manitoba)

soils was demonstrated by Bauer et al. (1966). At a given soil moisture supply yield of wheat was greater in fertilized soils. As the available moisture increased from 160 to 503 mm, yields increased about 910 kg on plots with no fertilizer while on plots with fertilizer, they increased by 1300 kg. Thus the increase in yield per unit increase in available water was greater on fertilized plots. Krogman (1967) found a similar trend with a mixed sward of orchard grass, creeping red fescue and brome grass fertilized with nitrogen and phosphorus.

Chapter 3

ANALYTICAL PROCEDURES

A. Soil Analysis

1. Soil pH

Soil pH was determined electrometrically by the method described by Peech (1965). Fifty ml of distilled water were added to 50 g air-dry soil and shaken for 30 minutes. The pH of the suspension was determined using a Beckman Zeromatic pH meter.

2. Soil Texture

Particle size analysis was performed by a standard pipette method (Kilner and Alexander, 1949).

3. Nitrate Nitrogen

NO_3-N was determined by Harpers' (1924) modified phenol disulphonic acid method. Ten (10 g) of air dry soil were extracted with 50 ml of solution containing 0.02 M $CuSO_4$ and 0.06% Ag_2SO_4. Nitrate was measured colorimetrically as nitrate form of phenol disulphonic acid in an alkaline solution using an ultraviolet spectrophotometer at 415 nm.

4. $NaHCO_3$ Extractable P

Phosphorus was measured using the acid molybdate method of Murphy and Riley (1962). Five grams (5 g) of air dry soil were extracted with 100 ml of 0.5 M $NaHCO_3$ extracting solution. The mixed molybdateascorbic acid reagent was used to reduce the phosphomolybdate complex and the absorbance of the blue color developed was measured using a spectrophotometer at 885 nm.

5. Inorganic Carbon

$CaCO_3$ was determined by Skinner et al. (1959) method. One gram of air dry soil was heated with 40 ml of 10% HCl for ten minutes. The CO_2 evolved was drawn by suction through a drying and absorption train consisting of concentrated H_2SO_4, a tube of dehydrite and calcium chloride. The amount of CO_2 evolved was determined by weighing the tube before and after trapping the gas. The results were expressed in percentage $CaCO_3$ equivalent.

6. Field Capacity

Soil samples (2 mm-size) from Portage la Prairie sites, were placed in plastic cylinders, the bottom of which were fitted with porous cloth. The surface of the samples were saturated with water and equilibrated for 48 hours. Tops of the cylinders were covered with parafilm to minimize surface evaporation. The moist soil was then subsampled, oven dried at 105°C and moisture content, so determined was expressed on oven dry soil basis. The moisture content was taken as the field capacity.

7. Permanent Wilting Percentage (P.W.P.)

This was determined by a pressure membrane method as described by Richards (1965).

8. Exchangeable K

Exchangeable K was extracted by Pratt (1965) modified procedure. A five-gram soil sample was shaken in 100 ml solution containing 1.0 N NH_4OAc and 250 ml $LiNO_3$ for one hour. The solution was filtered through Whatman No. 42 filter paper. Potassium concentration in the filtrate was determined using a Perkin-Elmer 303 Atomic Adsorption spectrophotometer.

B. Plant Analysis

1. Total P and Pdff

One gram oven dry ground plant tissues was digested using nitric acid and perchloric acid. The resulting digest was diluted with distilled water to 25 ml and filtered.

1.1 Phosphorus Derived from Fertilizer (Pdff)

- 1st Growth Chamber Experiment

From each sample 15 ml was drawn and put into a special container which was used to count radioactivity on the Beckman LS 7500 Liquid Scintillation System counter. Triplicate standards were made by diluting 0.2 ml of the original stock solution to 15 ml with distilled water. Background count was taken after each sample and subtracted. Phosphorus derived from fertilizer source was calculated as follows:

$$\text{P dff} = \frac{\text{Specific activity of } {}^{32}\text{p in a sample}}{\text{Specific activity of } {}^{32}\text{p of a standard}}$$

Total P derived from fertilizer source by the wheat plants was calculated by multiplying the above by the respective dry matter yield.

1.2 Total P - 1st Growth Chamber Experiment

To ensure uniformity and consistency, total P was determined using the same solution used for Pdff determination. Thus from 15 ml aliquot, 1 ml was drawn and diluted in 10 ml of distilled water and another dilution of 1 ml to 10 ml water followed. Two (2 ml) of previously prepared complexing reagent was added to each of the samples and left to stand while a blue colour developed as described by Stainton et al. (1974). After 15 minutes, readings were taken on a spectrophotometer at 885 nm. These readings were compared with a standard phosphate curve obtained by using phosphate solutions ranging from 0.1 to 10 ppm also complexed with mixed reagents. Total P in plant tissue was then calculated taking into consideration all the dilutions made.

1.3 Total P - Field and Lysimeter Experiments

The same procedure described in section (1) was followed with one exception. Since no Pdff was determined in this case, 1 ml which was diluted into 10 ml with distilled water was drawn from the original 25 ml filtrate unlike in section (1.1) where the 1 ml was drawn from the 15 ml used for counting the radioactivity.

2. Zinc, Copper, Mn and Fe

A one-gram sample of ground plant tissue was placed in a micro-kjeldhal flask, 10.0 ml of concentrated HNO_3 and 15 ml of 70% $HCLO_3$ were added. The mixture was digested until clear as described by Robert and Kerber (1980). The plant digest was tillered and made to 25 ml volume by adding distilled water. The copper, Zn, Fe and Mn concentrations in the solution were determined using Perkin-Elmer 303 Atomic Adsorption Spectrophotometer.

3. Potassium

A one-gram sample of ground tissue was placed in a micro-kjeldhal flask, 10.0 ml of concentrated HHO_3 and 15.0 ml of 70% $HCLO_3$ were added. The mixture was digested until clear. The digest was filtered and made to 25 ml volume by adding distilled water. A 1.0 ml aliquot of the above filtrate was diluted to 25 ml using 2.5 ml of a 2500 ppm $LiNO_3$ solution and 21.5 ml deionized water. The concentration of K was determined using a spectrophotometer.

4. Total Nitrogen

Total N was determined by a modified Kjeldahl method (Jackson, 1958).

Chapter 4

STUDY 1: FIRST GROWTH CHAMBER EXPERIMENT

Introduction

Phosphorus fertilization of field crops has become a routine practice over the years as farmers have tried to increase crop yields. However, response to P by crops has been variable from year to year depending on soil environment and on the amount of P added to soil as well as the type of crop grown. Soil moisture in particular, has a strong influence on the crop performance either by affecting the plant itself (Salim et al. 1965; Racz et al. 1974) and/or by affecting the supply of phosphorus to the plant (Cho et al. 1970; Hira and Singh, 1970). The effect of soil moisture on the supply of P to the plant is likely to be important for surface placed P as it is this region which dries out first.

In view of the above, an experiment was conducted to study the effect of (a) high and low soil moisture regimes, (b) different amounts of P added to soil, and (c) depth of P placement on dry matter yield and fertilizer P uptake by wheat plants.

The effect of soil moisture content, applied fertilizer P and depth of P incorporation on water use efficiency was also investigated.

Material and Methods

The soil used in this experiment was obtained from the Portage La Prairie area. Table 2 shows some of the physical and chemical properties. The Ap horizon soil was dried and sieved through a 2 mm sieve and then mixed thoroughly before being used.

Pots used in this experiment were cut from long plastic pipes with a cross-sectional area of 0.02 m^2. Each pot was 65 cm long. One end of each 65 cm pipe was sealed so that it could hold soil. Twelve kg of soil was used in each pot. The inner walls of the pipes were lined with plastic bags to ensure that no water and nutrient leakage took place from the soil. The soil column in each pot was 60 cm deep such that each 15 cm depth contained 3 kg of soil. The following procedure was followed in putting the soil into the pots. For the 0 - 15 cm P incorporation treatment 9 kg of non-P fertilized soil was put into the pot. Then above it, 3 kg of P fertilized soil were placed. For the 15 - 30 cm P incorporation treatment, 6 kg soil was put into the pot. Three kg of P fertilized soil was placed on top of these. Above it, 3 kg of nonP fertilized soil was placed.

Phosphorus was labelled with ^{32}p in form of ortho-phosphoric acid in order to quantify the amount of phosphorus derived by the wheat plants from the fertilizer. Ortho-phosphoric acid was added to 500 ml of deionized water and then one millicurrie of ^{32}p was added and the resulting solution shaken carefully. Some more water was added and mixed to make a 1,000 ml stock solution. The appropriate amount of ortho-phosphoric acid was used such that each 10 ml aliquot was equivalent to 100 ppm P on the basis of 3 kg soil. Appropriate volumes of tagged P were drawn from the stock solution and diluted with distilled water to make 50 ml solutions. The solution was sprayed onto the soil spread on brown paper and mixed thoroughly. Apart from phosphorus, each pot received the following nutrients prior to seeding: N as urea (100 ppm), K as K_2SO_4 (50 ppm), S as K_2SO_4 and $CuSO_4 \cdot 5H_2O$ (22 ppm), Cu as $CuSO_4 \cdot 5H_2O$ (4 ppm) based on the entire soil volume per pot. These nutrients were all dissolved in 2640 ml of distilled water and carefully poured into the pot containing 12 kg of soil. The 2640 ml water is the amount which was required to bring the soil in each pot to field capacity. Four weeks after seeding, each pot received an additional application of 50 ppm N (urea). Table 3 shows the treatments used in this experiment. Each treatment was replicated three times in a completely randomized design. Seeding of wheat (Triticum estivum var. Neepawa) was done on November 21, 1981 with emergence being observed 5 days later. Pots were watered on a daily basis to bring the soil to field capacity. The plants were thinned to four after 10 days. The moisture treatments were initiated 14 days after seeding. This consisted of two soil moisture regimes, low and high. Since the weight of individual pots and dry soil was taken at the beginning of the experiment before the 2640 ml of water/pot was added, it was possible to determine the amount of water used by the plants from each pot and on that basis, an appropriate quantity of water was added depending on moisture regime. The amount added was recorded.

(a) High soil moisture regime - By weighing the pots, appropriate amounts of water were added to bring the soil back to field capacity. Watering was done on a daily basis.

(b) Low soil moisture regime - Soil was allowed to dry until most of the plants showed signs of wilting before watering was done. By re-weighing the pots, appropriate quantity of water was added in each pot to bring the soil to 75% field capacity. The amount of water which was added was based on 12 kg soil. The same procedure was followed during the subsequent days, watering to bring the soil back to 75% field capacity being done only when the majority of the plants showed signs of wilting.

In both moisture regimes, an arbitrary quantity of water ranging from 10-100 g was added in the pots to take care of increased weight of pots due to plant growth. The quantity added into each pot varied with the amount of vegetative material in each pot. The conditions in the growth chamber were set as follows: temperature: 15°C (night), 23°C (day); daylength: 15 hours. The light-intensity ranged from 500-550 microeisteins $m^{-2}sec^{-1}$ within and above crop canopy. Humidity was not regulated because the controls on the cabinet were out of order.

Plant tops were harvested 42 days after seeding and dried in the oven at 60°C for 48 hours. The dry matter weights were determined and samples ground for laboratory analysis.

Table 2: Soil Characteristics for the First Growth Chamber Experiment

Location	Portage la Prairie
Series	Elm River
Sub-group	Cumulic Regosol
Texture	Sandy Loam
pH	7.2
$CaCO_3$	Low
$NaHCO_3$ Extr. P (0-15 cm)	4.5 (kg/ha)
NH_4Ac exch. K	260 (kg/ha)
NO_3-N (0-60 cm)	8.0 (kg/ha)

Note: Soil classification is based on Michalyna and Smith (1972) soils report.

Table 3: Treatments for the First Growth Chamber Experiment

Soil Moisture Regime	P-Added mg/pot	Depth of P-mixing (cm)
High	0	-
High	300	0 - 15
High	300	15 - 30
High	600	0 - 15
High	600	15 - 30
Low	0	-
Low	300	0 - 15
Low	300	15 - 30
Low	600	0 - 30
Low	600	15 - 30

RESULTS AND DISCUSSION

A. Dry Matter Yield

Dry matter yield for 42 days old wheat was significantly influenced by the soil moisture regimes and phosphorus added to soil but not by the depth of P incorporation (Table 4). Similarly phosphorus derived from fertilizer (Pdff) by the wheat plants was significantly influenced by the soil moisture regimes and rates of P added to soil but not by the depth of P incorporation (Table 6).

When no P was added to soil, the dry matter yields were very low and were not influenced by the soil moisture regimes. When P was added to soil, there was a significant dry matter-yield increase at both soil moisture regimes, but the increase was significantly larger at high soil moisture regime. At each soil moisture regime, the two depths of P incorporation were not significantly different in terms of influencing the dry matter yields. In high soil moisture regimes, the 600 mgP/pot resulted in a significantly higher dry matter yield over the 300 mgP/pots. In the low soil moisture treatment, the two rates of P added to soil were not significantly different in terms of increasing the dry matter yields.

With the exception of the check, total P in the above ground portion of wheat plants was significantly higher at high soil moisture conditions for both rates of P added to soil (Table 5). When no P fertilizer was added to soil, total P in the plant was not significantly affected by soil moisture conditions although the value was slightly higher when high soil moisture conditions were maintained. Total P in

Table 4: Dry Matter Yield (g/pot) as Affected by P Added to Soil, Depth of P Mixing and Soil Moisture Regimes

P Added (mg/pot)	Depth of Mixing (cm)	Soil Moisture Regimes	
		High	Low
		Dry Matter Yield (g/pot)	
0	-	12.3 a	10.0 a
300	0 - 15	34.4 c	22.7 b
300	15 - 30	33.7 c	20.7 b
600	0 - 15	39.9 d	24.9 b
600	15 - 30	40.8 d	23.4 b

Means with the same letter are not significantly different at 5% Tukey's Studentized Range.

Table 5: Total P Uptake as Affected by P Added to Soil, Depth of P Mixing and Soil Moisture Regimes

P Added (mg/pot)	Depth of Mixing (cm)	Soil Moisture Regimes	
		High	Low
		P Uptake (mg/pot)	
0	-	22.4 e	15.9 e
300	0 - 15	89.4 b	55.1 d
300	15 - 30	87.7 bc	55.3 d
600	0 - 15	125.0 a	76.1 bcd
600	15 - 30	134.0 a	70.5 cd

Means with the same letter are not significantly different at 5% Tukey's Studentized Range.

the plants was not affected significantly by depth of P incorporation but it was affected by the amount of P added to soil. The 300 mgP/pot significantly increased the total P in the plant both at high and low moisture regimes. The 600 mgP/pot rate resulted in a further significant increase of total P in the plant only at high soil moisture regime.

The Pdff was significantly higher at the high than at the low soil moisture levels (Table 6). At both soil moisture regimes the Pdff was significantly higher at the 600 mgP/pot rate than at the 300 mgP/pot. The depth of P incorporation had no significant effect on Pdff at both soil moisture regimes.

Phosphorus derived from the soil (Table 7) was generally higher in the high soil moisture treatments than in the low moisture treatments but the differences due to two moisture regimes were not statistically significant. The amount of P incorporated into soil and the depth of P incorporation did not affect phosphorus derived from soil significantly.

The absence of significant dry matter yield difference between soil moisture regimes in the check suggests that P was the most limiting growth factor in this case. However, when P was no longer the most limiting factor the low soil moisture could have affected dry matter yield either directly by affecting plant growth and/or by limiting P availability to the plants. The total P uptake and P derived from fertilizer by wheat shoots being higher in wheat grown in high moisture soil than in low moisture soil would tend to suggest that low soil moisture was limiting P uptake by wheat plants thereby limiting growth. Such observations were made by Olsen et al. (1961), Boatwright et al. (1964), Racz (1980). This was attributed to low diffusion of P at low

Table 6: Phosphorus Derived from Fertilizer (Pdff) as Affected by P Added to Soil Depth of P Incorporation and Soil Moisture Regimes

P Added (mg/pot)	Depth of Mixing (cm)	Soil Moisture Regime	
		High	Low
		Pdff	mgP/pot
300	0 - 15	68.1 c	39.2 a
300	15 - 30	60.6 c	34.0 a
600	0 - 15	92.1 e	55.1 c
600	15 - 30	102.0 e	49.6 b c

Means with the same letters are not significantly different at 5% Tukey's Studentized Range.

Table 7: Phosphorus Derived from Soil (Pdfs) as Affected by P Added to Soil, Depth of P Incorporation and Soil Moisture Regimes

P Added (mg/pot)	Depth of Mixing (cm)	Soil Moisture Regime	
		High	Low
		Pdfs	mgP/pot
0	-	22.4 a b	15.9 b
300	0 - 15	28.8 a b	15.9 b
300	15 - 30	27.1 a b	19.3 b
600	0 - 15	31.4 a b	21.6 a b
600	15 - 30	32.0 a b	20.9 a b

Means with the same letter are not significantly different at 5% Tukey's Studentized Range.

soil moisture. But, since the shoot P concentrations (Table 8) were above the critical level when P was added to soil, (Melsted et al., 1969), it is unlikely that the depression in dry matter yield under low soil moisture was due to P unavailability but a direct effect of moisture on the growth of the plant.

At both soil moisture regimes the Pdff when 300 mgP/pot was incorporated into 0-15 cm and 15-30 cm depths were not significantly different. Also when 600 mgP/pot was incorporated into the 0-15 cm and 15-30 cm depths, Pdff was not significantly different indicating that the plants were able to effectively utilize P placed in either depth.

The 600 mgP/pot rate significantly increased Pdff over the 300 mgP/pot rate at both soil moisture regimes, but a similar increase in dry matter yield was observed only in the high moisture treatment. The lack of dry matter yield increase in low soil moisture treatment despite the increase in Pdff was likely due to the direct effect of moisture stress on plant growth.

Table 8: Shoot P Concentration as Affected by P Added to Soil, Depth of P Mixing, and Soil Moisture Regimes (42 Days Old Wheat)

P Added (mg/pot)	Depth of P Mixing (cm)	Soil Moisture Regime	
		High	Low
		- - - - - %P - - - - -	
0	-	.17	.16
300	0 - 15	.26	.25
300	15 - 30	.26	.26
600	0 - 15	.31	.31
600	15 - 30	.33	.30

B. Water Use Efficiency

Water use efficiency was increased significantly by application of P fertilizer in P deficient soil both at high and low soil moisture (Table 9). However, water use efficiency due to 600 mgP/pot was not significantly different from that due to 300 mgP/pot application.

The depth of P incorporation had no significant effect on water use efficiency regardless of the soil moisture regime. Also water use efficiency was not significantly different at both high and low moisture regimes for both rates of P added to soil. The improved efficiency of water use in fertilized soils was reported earlier (Viets, 1962; Bauer et al., 1966; Krogman, 1967).

The effect of low soil fertility on plant growth was evident also from this experiment (Table 4) where with no P added to soil the dry matter yield was low regardless of the level of soil moisture. P additions encouraged better growth. With a well established plant canopy, it is likely that more water is lost from the soil-plant system by transpiration rather than evaporation from the soil surface. In such cases, water lost from the soil is probably proportional to the amount of vegetative parts which in turn are determined by the amount of water available for growth. This may explain why the difference in water use efficiency due to two moisture regimes was not significantly different once sufficient P was applied. The concept that water lost from the soil-plant system is proportional to the amount of vegetative material once soil fertility has been improved may also explain the lack of significant difference in water use efficiency due to depth of P incorporation.

Table 9: Moisture Use Efficiency as Affected by P Added to Soil, Depth of P Mixing and Low Soil Moisture

P Added (mg/pot)	Depth of Mixing (cm)	Soil Moisture Regime	
		High	Low
		kg d.m./ha/cm-H_2O	
0	-	156 c	180 b c
300	0 - 15	205 a b	228 a
300	15 - 30	216 a	220 a
600	0 - 15	230 a	224 a
600	15 - 30	223 a	233 a

Means with the same letter are not significantly different at 5% Tukey's Studentized Range.

Chapter 5

STUDY 2: FIELD EXPERIMENT

Introduction

It is well documented that to obtain maximum production of wheat, adequate amounts of fertilizer P and proper application techniques have to be employed as long as other factors are non-limiting. The amount of P required to attain maximum yields usually varies from place to place depending upon, among other things, the level of available P in that particular soil. In view of the above, the experiment was conducted to evaluate how limiting was P in the production of wheat under rain-fed conditions if other factors were close to optimum. Attention was paid mainly to (a) effect of rates of P broadcast and incorporated into soil, and (b) the depth of P incorporation on dry matter and grain yield. The effect of P banded with the seed was also investigated. This was to provide evidence as to whether this practice was really necessary even when large amounts of P had been incorporated into soil.

Materials and Methods

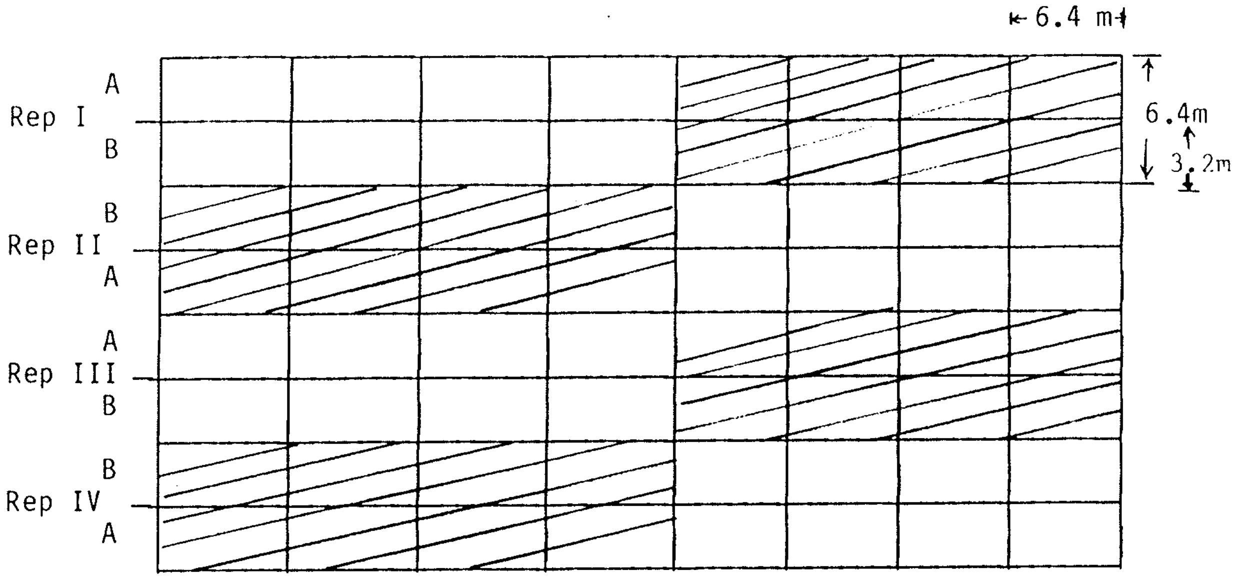
The field experiment was initiated in spring of 1982 on three sites chosen mainly on the basis of their soil P contents and geographical location. The Haywood site was low in available P, while Elm Creek and Winkler sites had medium to high levels of available P. Table 10 shows some of the chemical and physical properties of soils used in this study.

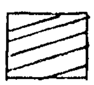
A split split plot design was used with four replicates at each site. The field layout is shown in Figure 1. Each replicate (block) was 51.2 m long by 6.4 m wide. Each replicate was divided into two equal main plots on the basis of depth of P incorporation. The main plots were divided into 4 sub-plots of 6.4 m by 6.4 m. Phosphorus (MCP) at the rate of 0, 50, 100 and 200 KgP/ha was hand broadcast randomly in four sub-plots of each main plot. The P fertilizer in four sub-plots of one main plots (shaded) were rotor-tilled to the depth of 15 cm. Nitrogen (NH_4NO_3) and potassium (KCl) were later hand broadcast and rotor-tilled to 7.5 cm deep, this time in both main plots. At all three sites, potassium was added at the rate of 200 kg/ha. Nitrogen was added at the rate of 150 kg/ha at Haywood and Winkler sites and 200 kg/ha at the Elm Creek site. The relative amounts of N and K added to soil were based on relative amounts of available N and K as determined by soil tests so that these elements were not limiting. At the time of seeding, the subplots were split into halves lengthwise (A and B), making 8 sub sub-plots per main plot or 16 sub-subplots per block. All sub-sub plots on one-half of each block (lengthwise) received an extra 17 KgP/ha and 33 Kgk/ha which were banded with the seed at the depth of 2.5 cm. On the other half of the block, seeding was done in the same manner except that no extra P was banded with the seed. The treatments are shown in Table 11. Each treatment constituted 18 rows. These were achieved by making two runs with a 9 row seed drill. To avoid contamination, all plots on one side of each of the four blocks that received the banded P and K were seeded first. The drill was then cleaned before being used to band the 33 KgK/ha with the seed on the remaining half of each block. At all sites, wheat (Triticum estevum var. Columbus) was seeded at the rate of 100 kg/ha.

Above ground wheat samples for each treatment were harvested from 1 m^2 area when wheat was 28, 42, 56 and 74 days old. The stages of growth corresponding to the above days are shown in Table 12. The final samples were taken at maturity. All samples were dried in the drying room at a temperature of 60°C and dry matter yields were determined. At maturity, grain yields were determined. Tissue analysis for P, K, Zn, Cu, Fe and Mn in the above ground portion of the plants and grain was also made but this time on a composite sample from four replicates for each treatment.

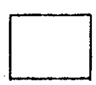
Grain yield for most treatment combinations were plotted against corresponding P shoot concentrations for 28, 42, 56 and 74 days old wheat. Potassium, nitrogen and some micronutrient contents in the shoots and grain were determined simply to identify any other element that may have limited growth apart from phosphorus. More attention was paid to zinc and copper because earlier studies (McKenzie, 1980; Wallace et al., 1978; Loneragan et al., 1979) have shown that high levels of P may induce Zn and Cu deficiencies. Wheat shoot nutrient concentrations determined at boot and heading stages were mostly used for the discussions because literature regarding the critical levels and nutrient concentration ranges for other growth stages was very limited.

Figure 1: Field Experiment Layout





0 - 15 cm Depth of P incorporation



0 - 7.5 cm Depth of P incorporation

A: 33 KgK/ha was banded with the seed in A-rows
B: 17 kgP/ha + 33 KgK/ha were banded with the seed in B-rows

Table 10: Some of the Characteristics of Soils Used for Field Experiments

Location	Haywood[1]	Elm Creek[1]	Winkler[2]
Soil Series	Almassipi	Elm Creek	Rignold
Sub-Group	Gleyed-Carbonated Rego Black	Orthic-Black	Gleyed Black
Texture	V.F.S.	F.S. - L.V.F.S	V.F.S.L.
Carbonate-Content	Low	Low	Low
pH	8.1	8.2	8.0
NO_3-N (kg/ha) (0-60 cm)	84	42	125
Available P (kg/ha) (0-15 cm)	6	25	31
Available K (kg/ha) (0-15 cm)	146	449	602

1. Soil Classification by Michalyna and Smith (1972).

2. Soil Classification by Smith and Michalyna (1973).

Table 11: Treatment Structure for the Field Experiment

Depth of P-mixing (cm)	P-broadcast and mixed with soil (kg/ha)	P-banded with the seed (kg/ha)
-	0	0
-	0	17
0 - 7.5	50	0
0 - 7.5	50	17
0 - 7.5	100	0
0 - 7.5	100	17
0 - 7.5	200	0
0 - 7.5	200	17
0 - 15	50	0
0 - 15	50	17
0 - 15	100	0
0 - 15	100	17
0 - 15	200	0
0 - 15	200	17

Table 12: Sampling Days After Seeding and Corresponding Stages of Growth

Sampling No.	Days After Seeding	Stage of Growth[1]
1	28	Early Tillering
2	42	Boot
3	56	Heading
4	74	Milk
5	95	Mature

1. Based on Visual Observation.

RESULTS AND DISCUSSION

A. Plant Appearance

Seed germination and emergence was good. Soil moisture at seeding as well as growing season rainfall and its distribution are presented in Appendix 1 and 2. At Haywood site, the water table was about 1.5 m below the soil surface. No delayed emergence or seed injuries due to high rates of P were observed at all three sites. There were no visual P deficiency symptoms at Winkler and Elm Creek sites. However, the stunted growth and poor tillering characteristics of P deficient wheat plant were apparent at Haywood site 4 weeks after seeding when no phosphorus was added to soil. The symptoms persisted throughout the season. No visual deficient symptoms for other nutrients were evident at any of the sites. At heading stage, there was a severe lodging of plants at the Winkler site. About 80 percent of the plants were affected. Plants at Elm Creek and Haywood were free from lodging.

B. Yields

Haywood

There was a significant dry matter yield increase to P broadcast and incorporated into soil prior to seeding. Phosphorus banded with the seed also had a significant influence on dry matter yield. But the depth of P incorporation did not affect dry matter yield significantly at any stage of growth (Tables 13 to 18). Since the effect of the depth of P incorporation on dry matter-yield response was not significant, the numbers of observations per treatment was increased from four to eight by combining the results from the two depths. Thus each mean in Tables 13a, 14a, 15a, 16a and 17a are comprised of 8 observations. With the exception of the samples taken at the milk stage (Table 16a), there was a significant interaction between P broadcast and P banded with the seed.

When P was not banded with the seed, there was a significant dry matter yield increase for the 50 kgP/ha rate at all samplings except at early tillering. The 100 kgP/ha rate resulted in a significant yield increase over that of 50 kgP/ha at all sampling stages except at the milk stage (Table 16a). The addition of 200 kgP/ha resulted in a further significant yield increase only at the boot stage (Table 14a).

When 17 kgP/ha was banded with the seed, there was a significant yield increase over the check at all stages of growth. When 50 kgP/ha was mixed with soil prior to seeding, the P banded with the seed increased dry matter yield significantly at all samplings with an exception of the sample taken at the boot stage (Table 14a). When P was banded with the seed into soil which received 100 kgP/ha prior to seeding, there was a significant dry matter yield increase to banded P only for wheat samples taken at the early tillering and milk stages (Tables 13a and 16a). When P was banded with the seed into soil which was initially mixed with 200 kgP/ha, there was a significant yield increase to banded P only at the milk stage. As was the case with dry matter yield, the depth of P incorporation did not affect grain yield significantly (Table 18). The effect of P mixed with soil was highly significant (P=0.01). Also, the interaction effect of P mixed with soil and P banded with the seed on grain yield was highly significant. How-

Table 13: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Early Tillering (Haywood)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded into the Seed (kg/ha)	
		0	17
		Dry Matter Yield	
0 - 7.5	0	117	145
	50	100	145
	100	136	178
	200	156	153
0 - 15	0	91	124
	50	113	141
	100	134	141
	200	157	157

Depth of P Mixing:	N.S.
P Mixed with Soil:	Significant P = 0.01
P Banded with the Seed:	Significant P = 0.05
P Mixed with Soil X P Banded:	Significant P = 0.05

Table 13a: Influence of P Mixed with Soil and P Banded with the Seed on Dry Matter Yield (kg/ha) over two Depths of P-mixing - Early Tillering Stage (Haywood)

P Mixed (kg/ha)	P Banded with the Seed (kg/ha)	
	0	17
	Dry Matter Yield (kg/ha)	
0	101 A a	135 b
50	106 A a	144 b
100	135 B a	159 b
200	156 C a	156 a

Means with the same capital letter are not significantly different at 5% Tukey's Studentized Range.

Means with the same small letter in each row are not significantly different at 5% Tukey's Studentized Range.

Table 14: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Boot Stage (Haywood)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded into the Seed (kg/ha)	
		0	17
		Dry Matter Yield	
0 - 7.5	0	430	922
	50	766	1058
	100	1766	1245
	200	1381	1348
0 - 15	0	351	761
	50	918	1121
	100	1216	1083
	200	1374	1287

Depth of P Mixing: N.S.
P Mixed with Soil: Significant P = 0.01
P Banded with the Seed: Significant P = 0.01
P Mixed with Soil X P Banded: Significant P = 0.01

Table 14a: Influence of P Mixed with Soil and P Banded with the Seed on Dry Matter Yield (kg/ha) over two Depths of P-mixing - Boot Stage (Haywood)

P Mixed (kg/ha)	P Banded with the Seed (kg/ha)	
	0	17
	Dry Matter Yield (kg/ha)	
0	390 A a	841 b
50	842 B a	1082 b
100	1196 C a	1164 a
200	1378 D a	1318 a

Means with the same capital letter are not significantly different at 5% Tukey's Studentized Range.

Means with the same small letter in each row are not significantly different at 5% Tukey's Studentized Range.

Table 15: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Heading Stage (Haywood)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded into the Seed (kg/ha) 0	17
		Dry Matter Yield	
0 - 7.5	0	2332	3604
	50	3468	3723
	100	4129	4440
	200	4740	4062
0 - 15	0	2046	3224
	50	3529	3919
	100	4543	4174
	200	4871	4687

Depth of P Mixing: N.S.
P Mixed with Soil: Significant P = 0.01
P Banded with Seed: N.S.
P Mixed with Soil X P Banded: Significant P = 0.05

Table 15a: Influence of P Mixed with Soil and P Banded with the Seed on Dry Matter Yield (kg/ha) over two Depths of P-Mixing - Heading Stage (Haywood)

P Mixed (kg/ha)	P Banded with the Seed (kg/ha) 0	17
	Dry Matter Yield (kg/ha)	
0	2189 A a	3414 b
50	3498 B a	3821 b
100	4336 C a	4307 a
200	4405 C a	4375 a

Means with the same capital letter are not significantly different at 5% Tukey's Studentized Range.

Means with the same small letter in each row are not significantly different at 5% Tukey's Studentized Range.

Table 16: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Milk Stage (Haywood)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded With the Seed (kg/ha)	
		0	17
		Dry Matter Yield	
0 - 7.5	0	4980	6782
	50	6900	8127
	100	7630	7972
	200	7812	8650
0 - 15	0	3790	6852
	50	7097	7292
	100	7082	8070
	200	7537	8785

Depth of P Mixing: N.S.
P Mixed with Soil: Significant $P = 0.01$
P Banded with Seed: Significant $P = 0.01$
P Mixed with Seed x P Mixed with Soil: N.S.

Table 16a: Influence of P Mixed with Soil and P Banded with the Seed on Dry Matter Yield (kg/ha) over two Depths of P-mixing - Milk Stage (Haywood)

P Mixed (kg/ha)	P Banded with the Seed (kg/ha)	
	0	17
	Dry Matter Yield (kg/ha)	
0	4385 A a	6817 b
50	6998 B a	7710 b
100	7356 B a	8021 b
200	7675 B a	8717 b

Means with the same capital letter in each row are not significantly different at 5% Tukey's Studentized Range.

Means with the same small letter in each row are not significantly different at 5% Tukey's Studentized Range.

Table 17: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - At Maturity (Haywood)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded With the Seed (kg/ha) 0	17
		Dry Matter Yield	
0 - 7.5	0	4925	7282
	50	6837	8120
	100	8327	8062
	200	8177	8212
0 - 15	0	4607	6625
	50	6455	8280
	100	7795	8347
	200	7877	8207

Depth of P Mixing: N.S.
P Mixed with Soil: Significant P = 0.01
P Banded with Seed: Significant P = 0.01
P Mixed with Soil x P Banded: Significant P = 0.05

Table 17a: Influence of P Mixed with Soil and P Banded with the Seed on Dry Matter Yield (kg/ha) over two Depths of P-mixing - At Maturity (Haywood)

P Mixed (kg/ha)	P Banded with the Seed (kg/ha) 0	17
	Dry Matter Yield (kg/ha)	
0	4766 A a	6953 b
50	6646 B a	8200 b
100	8061 C a	8205 a
200	8027 C a	8207 a

Means with the same capital letter are not significantly different at 5% Tukey's Studentized Range.

Means with the same small letter in each row are not significantly different at 5% Tukey's Studentized Range.

ever, the effect of P banded with the seed was not significant mainly because higher rates of P mixed with soil resulted in grain yield depressions. Banding P with the seed in such cases accentuated the problem while it was quite the opposite at lower rates of P. This was evident from Table 6a and Fig. 2. Since the depth of P incorporation was not significant the means for each treatment in Table 6a are also averages of 8 observations. With no P banded with the seed, there was a significant grain yield response to 50 kgP/ha and 100 kgP/ha mixed with soil. Addition of 200 kgP/ha resulted in a significantly lower yield compared to that obtained with 100 kgP/ha rate. In fact, the 200 kgP/ha was no more effective than 50 kgP/ha application (Table 18a, Fig. 2).

When 17 kgP/ha was banded with the seed, there was a significant grain yield increase to banded P over the check where no P was added to soil. When P was banded with the seed in soil into which 50 kgP/ha was incorporated prior to seeding, it increased grain yield significantly. Banding P with the seed in soil which received 100 kgP/ha prior to seeding did not affect grain yield significantly. However, the banding of P with the seed in soil into which 200 kgP/ha was initially incorporated resulted in a significant yield depression (Table 18a). The maximum grain yield for this site was obtained with 100kgP/ha broadcast and incorporated into soil which gave about the same yield as banding 17 kgP/ha with the seed in soil into which only 50 kgP/ha was broadcast and worked in prior to seeding (Fig. 2).

The P concentrations in shoots and uptakes did not show any apparent differences due to depth of P incorporation throughout the growing period (Table 20). This may partly explain the lack of significant influence of depth of P incorporation on yield. P concentrations and uptakes both in vegetative parts and grain tended to increase as the amount of P incorporated into soil increased up to the 100kgP/ha rate (Table 21). The differences in P concentrations and uptakes at the 100 kgP/ha rate and 200 kgP/ha rate were generally small. This may help to account for the dry matter and grain yield responses to rates of P up to 100 kgP/ha and lack of further dry matter yield increase due to the 200 kgP/ha rate. P banded with the seed generally increased P uptake when it was banded in soil into which 50 kgP/ha or less was incorporated into soil prior to seeding (Table 21). This indicated that banded P was more available to the plant only when low rates of P are mixed with soil. The above may explain the dry matter and grain yield response to banded P observed only when P was banded with the seed in soil into which 50 kgP/ha or less was incorporated prior to seeding.

The grain yield depression observed at the 200 kgP/ha rate (Table 18a) could not be explained by seed and seedling injuries as the result of P because no significant dry matter-yield depression was observed during the early stages of growth. Also, the biological yield at the final harvest was not depressed by high P rates. The declining trends of harvest index (Table 19) also suggest that factors other than seed injury affected grain yields. Copper deficiency for example, has been found to decrease the harvest index by affecting grain formation (Scharrer and Schauromloffel, 1960; Brown and Clark, 1977). Copper concentrations and uptakes were thus examined to see if Cu might have been limiting. Grain Cu contents showed a declining trend as the amount of P broadcast and incorporated into soil prior to seeding increased (Table

Table 18: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Grain Yield (kg/ha) (Haywood)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded into the Seed (kg/ha)	
		0	17
		Grain Yield	
0 - 7.5	0	1557	1987
	50	2324	2470
	100	2911	2589
	200	2409	1596
0 - 15	0	1470	1933
	50	2151	2920
	100	2472	2682
	200	2114	1841

Depth of P Mixing: N.S.
P Mixed with Soil: Significant P = 0.01
P Banded with Seed: N.S.
P Mixed with Soil x P Banded: Significant P = 0.01

Table 18a: Influence of P Mixed with Soil and P Banded with the Seed on Grain Yield (kg/ha) over two Depths of P-mixing (Haywood)

P Mixed (kg/ha)	P Banded with the Seed (kg/ha)	
	0	17
	Grain Yield (kg/ha)	
0	1514 A a	1961 b
50	2238 B a	2695 b
100	2692 C a	2635 a
200	2261 B b	1825 a

Means with the same capital letter are not significantly different at 5% Tukey's Studentized Range.

Means with the same small letter in each row are not significantly different at 5% Tukey's Studentized Range.

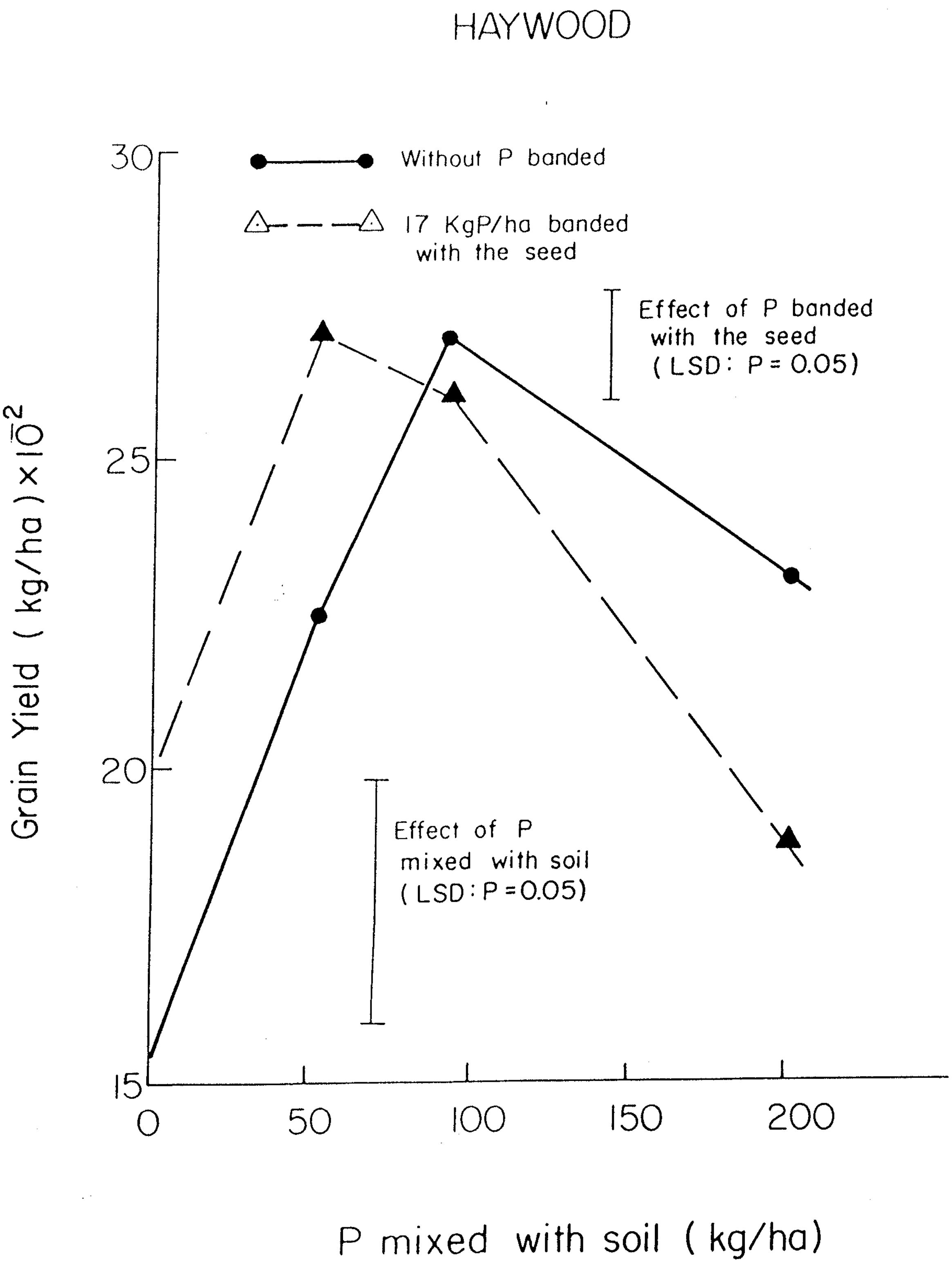


Figure 2: Influence of P Mixed with Soil Prior to Seeding and P Banded with the Seed on Grain Yield

Table 19: Effect of P Mixed with Soil and P Banded with the Seed on Harvest Index

Site	P Added and Mixed with Soil (kg/ha)	P Banded With the Seed (kg/ha)	
		0	17
Haywood	0	32.0	28.2
	50	33.6	32.8
	100	33.4	32.1
	200	28.0	21.0
Winkler	0	33.1	32.4
	50	29.6	30.5
	100	29.0	30.0
	200	27.5	28.2
Elm Creek	0	38.7	38.0
	50	39.7	38.1
	100	38.5	38.0
	200	38.2	39.0

Table 20: P Concentration and Uptake As Influenced by the Depth of P Incorporation

Stage of Growth	Depth of P Incorp. (cm)	P Mixed with Soil (kg/ha)			
		0	50	100	200
Early Tillering	0 - 7.5	0.24(.28)	0.33(.33)	0.45(.61)	0.49(.76)
	0 - 15	0.25(.23)	0.36(.40)	0.47(.62)	0.51(.80)
Boot	0 - 7.5	0.18(.77)	0.24(1.8)	0.31(3.6)	0.35(4.8)
	0 - 15	0.18(.63)	0.23(2.0)	0.31(3.8)	0.32(4.4)
Heading	0 - 7.5	0.18(4.2)	0.20(6.9)	0.23(9.5)	0.24(11.4)
	0 - 15	0.17(3.5)	0.21(7.4)	0.24(10.9)	0.23(11.2)
Milk	0 - 7.5	0.12(6.0)	0.16(11.0)	0.17(13.0)	0.18( )
	0 - 15	0.16(6.1)	0.16(11.4)	0.20(14.2)	0.19(14.3)

Note:
(1) Numbers in brackets = P uptake (kg/ha)
(2) Numbers outside the brackets = P concentration (%P)

Table 21: P Uptake and Concentration As Influenced by Amount of P Mixed with Soil and P Banded with the Seed

Stage of Growth	P Banded kg/ha	P Mixed with Soil (kg/ha)			
		0	50	100	200
			P*		
Early Tillering	0	0.25(.25)	0.35(.37)	0.46(.62)	0.50(.78)
	17	0.34(.45)	0.38(.54)	0.44(.69)	0.44(.68)
Boot	0	0.17(.66)	0.26(2.2)	0.34(4.1)	0.33(4.5)
	17	0.20(1.7)	0.27(2.9)	0.28(3.8)	0.29(3.8)
Heading	0	0.16(4.4)	0.19(6.6)	0.24(10.4)	0.26(11.5)
	17	0.19(6.5)	0.22(8.4)	0.26(11.2)	0.26(11.4)
Milk	0	0.14(6.1)	0.16(11.2)	0.18(13.2)	0.19(14.6)
	17	0.13(8.8)	0.17(13.1)	0.17(13.6)	0.19(16.0)
Grain	0	0.26(3.9)	0.33(7.4)	0.34(9.2)	0.36(8.1)
	17	0.31(6.1)	0.32(8.6)	0.31(8.2)	0.38(6.5)
Straw	0	0.03(.97)	0.03(1.3)	0.04(2.1)	0.06(3.4)
	17	0.03(1.5)	0.03(1.7)	0.03(1.6)	0.04(2.6)

* Numbers in brackets = P Uptake (kg/ha)
Numbers outside brackets = P concentration (% P)

Table 22: Cu Concentration and Uptake As Influenced by Amount of P Mixed with Soil and P Banded with the Seed Over Two Depth of P Incorporation

Stage of Growth	P Banded kg/ha	P Mixed with Soil (kg/ha)			
		0	50	100	200
			Shoot Cu*		
Early Tillering	0	5.1 (.55)	5.0 (.53)	5.2 (.71)	5.5 (.86)
	17	5.4 (.74)	5.3 (.77)	6.0 (.96)	6.0 (.94)
Boot	0	3.4 (2.33)	3.4 (2.93)	3.7 (4.47)	3.5 (4.9)
	17	3.7 (3.17)	3.7 (4.10)	4.0 (4.75)	4.2 (5.6)
Heading	0	3.1 (11.2)	3.5 (12.2)	2.5 (11.1)	2.0 (9.0)
	17	2.9 (9.9)	3.0 (11.4)	2.7 (11.0)	1.9 (8.3)
Milk	0	3.1 (13.8)	2.2 (15.8)	2.0 (14.3)	1.8 (14.4)
	17	2.4 (16.2)	2.3 (18.4)	1.9 (15.0)	1.7 (15.2)
Grain	0	5.6 (8.5)	3.7 (8.4)	2.6 (6.9)	2.0 (4.5)
	17	4.9 (9.6)	3.5 (9.4)	3.1 (8.2)	2.2 (4.0)
Straw	0	2.0 (6.5)	1.5 (6.6)	1.4 (7.5)	1.1 (6.5)
	17	2.0 (10.0)	1.8 (9.6)	1.9 (9.1)	1.4 (8.9)

(1) Numbers in brackets are Cu Uptake (g/ha)
(2) Numbers outside the brackets are Cu concentration (ppm)

22). Grain Cu concentration declined from about 5 to 2 ppm as the amount of P incorporated into soil prior to seeding increased from 0 to 200 kgP/ha. Although there was a general decline in grain Cu concentration as the rates of P increased the differences in total Cu uptake up to the 100 kgP/ka rate was small because yield was increasing up to 100 kgP/ha. However, there was a two-fold decline in total grain Cu uptake when the 200 kgP/ha rate is compared with other rates of P. The decline in this case was mainly due to low [Cu] and low grain yield. There was no observable influence of P banded with the seed on either Cu concentration in grain or grain Cu uptake. All shoot Cu concentration at boot stage were marginal according to the 5.0 ppm Cu suggested by Melsted et al. (1969) but optimum according to the 3.3 ppm Cu listed by Gupta and McLeod (1970) and low according to McAndrew (1969).

At heading and milk stages of growth, there was a consistent declining trend of Cu concentration as the rates of P broadcast increased (Table 22). The decrease was mostly due to biological dilution because the total Cu uptake was little affected. P banded with the seed had little effect on copper concentration or uptake. Although no reliable critical values for wheat at heading and milk stages could be found, the Cu concentration at the 200 kgP/ha rate was much lower than those recorded at Elm Creek and Winkler sites for the same rate of P broadcast (Tables 32 and 44).

Low [Cu] in shoots because of biological dilution and relatively low grain Cu concentration and uptake tended to suggest that copper might have been deficient at the 200 kgP/ha rate and might have been the cause of lower harvest index at the 200 kgP/ha rate than at other rates. It is not clear as to why grain yield depression was accentuated when 17 kgP/ha was banded with the seed in soil into which 200 kgP/ha was incorporated prior to seeding because copper concentrations and uptakes both in vegetative and grain at the 200 kgP/ha rate with and without P banded were almost the same.

Zinc concentration in shoots tended to decrease when P was broadcast and also when P was banded compared to the check (Table 23) at the heading and milk stages. However, the decrease was mainly due to biological dilution as the result of increased growth due to P additions because the Zn uptakes were almost the same. At earlier stages of growth, the Zn concentrations were relatively uniform at all treatments but the uptakes tended to increase with increase in amount of P broadcast and incorporated prior to seeding. P banded with the seed increased Zn uptake only when P was not incorporated into soil prior to seeding. The increase in Zn uptakes was probably due to earlier establishment of a good root system as the result of P additions. Although [Zn] in grain tended to decrease with increase in rates of P broadcast, the uptakes were almost the same up to the 100 kgP/ha rate. The low Zn uptake at the 200 kgP/ha was mainly due to low grain yield recorded for this rate. P banded with the seed had little influence on either zinc concentration or uptake (Table 23). Despite some variations in zinc concentrations and uptakes in vegetative and grain, zinc did not seem to have been limiting. For example, at boot and heading stages, zinc concentrations in shoots were above the 15 ppm critical values listed by Melsted et al. (1969) and Ward et al. (1973) respectively for all treatments.

Table 23: Zn-Concentration and Uptake As Influenced by Amount of P Mixed with Soil and P Banded with the Seed

Stage of Growth	P Banded kg/ha	P Mixed with Soil (kg/ha)			
		0	50	100	200
			Zn*		
Early Tillering	0	27 (2.7)	27 (2.8)	28 (3.8)	28 (4.4)
	17	27 (3.6)	25 (3.6)	27 (4.3)	28 (4.4)
Boot	0	21 (8.2)	20 (16.8)	19 (22.7)	18 (24.8)
	17	17 (14.3)	19 (20.7)	18 (20.9)	18 (27.7)
Heading	0	26 (58.0)	18 (61.6)	16 (66.8)	15 (65.5)
	17	18 (62.1)	15 (56.9)	16 (70.6)	15 (65.2)
Milk	0	18 (78.9)	10 (69.9)	10 (73.0)	10 (76.0)
	17	14 (95.4)	12 (92.5)	9 (72.8)	10 (87.2)
Grain	0	39 (60.1)	27 (60.6)	21 (56.0)	21 (49.0)
	17	35 (68.1)	26 (69.0)	26 (68.0)	20 (34.0)
Straw	0	10 (32.5)	5 (22.0)	4 (21.5)	5 (28.8)
	17	6 (29.9)	4 (22.0)	4 (22.2)	3 (19.5)

* Numbers in brackets are Zn Uptake (g/ha)
Numbers outside the brackets are shoot [Zn] (ppm)

Table 24: Nitrogen, K, Mn and Fe Concentrations As Influenced by Amount of P Mixed with Soil and P Banded with the Seed

Stage of Growth	P Banded (kg/ha)	P Mixed with Soil (kg/ha)			
		0	50	100	200
			%N		
Heading	0	2.3	2.5	2.7	2.7
	17	2.8	2.5	2.6	2.6
Grain	0	3.1	3.0	3.2	3.1
	17	3.1	3.1	3.1	3.2
			%K		
Heading	0	1.76	1.72	1.59	1.61
	17	1.44	1.47	1.74	1.68
			Mn(ppm)		
Boot	0	25.0	26.5	26.5	28.0
	17	31.4	33.7	31.4	31.5
			Fe(ppm)		
Boot	0	161	173	166	168
	17	165	162	176	156

Nitrogen, K, Mn and Fe were present in sufficient quantities (Table 24). Ward et al. (1973) indicated N and K sufficiency level in spring wheat at head emergence as 2-3% N and 1.5-3% K respectively. Melsted et al. (1969) listed Mn and Fe critical levels for wheat at boot stage as 30 and 25 ppm respectively. Manganese concentrations in this study were close to the critical value. Iron concentrations were well above the critical value.

<u>Elm Creek</u>

The depth of P incorporation did not affect the dry matter yield significantly for any of the five harvests nor did it affect grain yield (Tables 25 to 30). Where the other treatments were significant the results from the two depths were combined making a total of 8 observations per treatment. Phosphorus banded with the seed had no significant effect on dry matter yield at any of the five harvests nor did it affect grain yield (Table 30 and Fig. 3). However, P incorporated into soil prior to seeding was found to affect the dry matter yield at the boot, heading and milk growth stages, but not at the early tillering stage nor when wheat was fully mature. Phosphorus incorporated into soil prior to seeding also had no significant effect on grain yield (Table 30 and Fig. 3).

At boot and heading stages of growth, there was a significant dry matter yield increase due to the addition of 50 kgP/ha but the increase was not found to be significant at the milk stage (Tables 26a, 27a, and 29a). At the milk stage, 100kgP/ha was required in order to obtain a significant dry matter yield increase. Any further increase in dry

Table 25: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Early Tillering (Elm Creek)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded With the Seed (kg/ha)	
		0	17
		Dry Matter Yield	
0 - 7.5	0	160	173
	50	199	179
	100	183	213
	200	177	168
0 - 15	0	135	172
	50	146	150
	100	157	170
	200	178	208

None of the treatment was significant.

Table 26: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Boot Stage (Elm Creek)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded With the Seed (kg/ha) 0	17
		Dry Matter Yield	
0 - 7.5	0	1003	1141
	50	1402	1202
	100	1204	1369
	200	1294	1408
0 - 15	0	914	923
	50	1284	1277
	100	1345	1436
	200	1373	1404

Depth of P Mixing: N.S.
P Banded with Seed: N.S.
P Mixed with Soil: Significant P = 0.01

Table 26a: Influence of P Mixed with Soil and P Banded with the Seed On Dry Matter Yield (kg/ha) over two Depths of P-mixing - Boot Stage (Elm Creek)

P Mixed (kg/ha)	P Banded with the Seed[1] (kg/ha) 0	17	Main Effect of P Mixed with Soil[2]
	Dry Matter Yield (kg/ha)		
0	958 a	1032 a	995 a
50	1343 a	1239 a	1291 b
100	1345 a	1402 a	1373 b
200	1334 a	1406 a	1370 b

Means with the same letter in each row (1), and this column (2) are not significantly different at 5% Tukey's Studentized Range.

Table 27: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Heading Stage (Elm Creek)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded into the Seed (kg/ha)	
		0	17
		Dry Matter Yield	
0 - 7.5	0	3595	3721
	50	4107	3769
	100	3924	3563
	200	3774	3963
0 - 15	0	3359	3533
	50	4060	3913
	100	3780	4284
	200	3958	3902

Depth of P Mixing: N.S.
P Banded with Seed: N.S.
P Mixed with Soil: Significant P = 0.05

Table 27a: Influence of P Mixed with Soil and P Banded with the Seed On Dry Matter Yield (kg/ha) over two Depths of P-mixing - Heading Stage (Elm Creek)

P Mixed (kg/ha)	P Banded with the Seed[1] (kg/ha)		Main Effect of P Mixed with Soil[2]
	0	17	
	Dry Matter Yield (kg/ha)		
0	3477 a	3627 a	3552 a
50	4083 a	3841 a	3962 b
100	3852 a	3923 a	3888 b
200	3866 a	3932 a	3899 b

1 Means with the same letter in each row are not significantly different at 5% Tukey's Studentized Range.
2 Means with the same letter in this column are not different at 5% Tukey's Studentized Range.

Table 28: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Milk Stage (Elm Creek)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded With the Seed (kg/ha)	
		0	17
		Dry Matter Yield	
0 - 7.5	0	9145	9170
	50	9705	8657
	100	9715	10432
	200	9642	9555
0 - 15	0	8637	9905
	50	9102	10390
	100	9930	9810
	200	10095	10827

Depth of P Mixing: N.S.
P Banded with Seed: N.S.
P Mixed with Soil: Significant P = 0.05

Table 28a: Influence of P Mixed with Soil and P Banded with the Seed On Dry Matter Yield (kg/ha) over two Depths of P-mixing - Milk Stage (Elm Creek)

P Mixed (kg/ha)	P Banded with the Seed[1] (kg/ha)		Main Effect of P Mixed with Soil[2]
	0	17	
	Dry Matter Yield (kg/ha)		
0	8891 a	9537 a	9214 a
50	9464 a	9523 a	9493 ab
100	9972 a	10121 a	10046 b
200	10030 a	10191 a	10110 b

Means with the same letter in each row (1), and this column (2) are not significantly different at 5% Tukey's Studentized Range.

Table 29: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - At Maturity (Elm Creek)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded into the Seed (kg/ha)	
		0	17
		Dry Matter Yield	
0 - 7.5	0	9260	9620
	50	8755	8657
	100	10012	9367
	200	8767	8777
0 - 15	0	8660	9610
	50	8632	9975
	100	8645	10270
	200	10455	9425

None of the treatments had a significant effect on dry matter yield at 5% Tukey's Studentized Range.

Table 30: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Grain Yield (kg/ha) (Elm Creek)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded into the Seed (kg/ha)	
		0	17
		Grain Yield	
0 - 7.5	0	3572	3562
	50	3460	3420
	100	3902	3602
	200	3442	3430
0 - 15	0	3280	3745
	50	3452	3682
	100	3290	3848
	200	3915	3692

None of the treatments had a significant affected grain yield at 5% Tukey's Studentized Range.

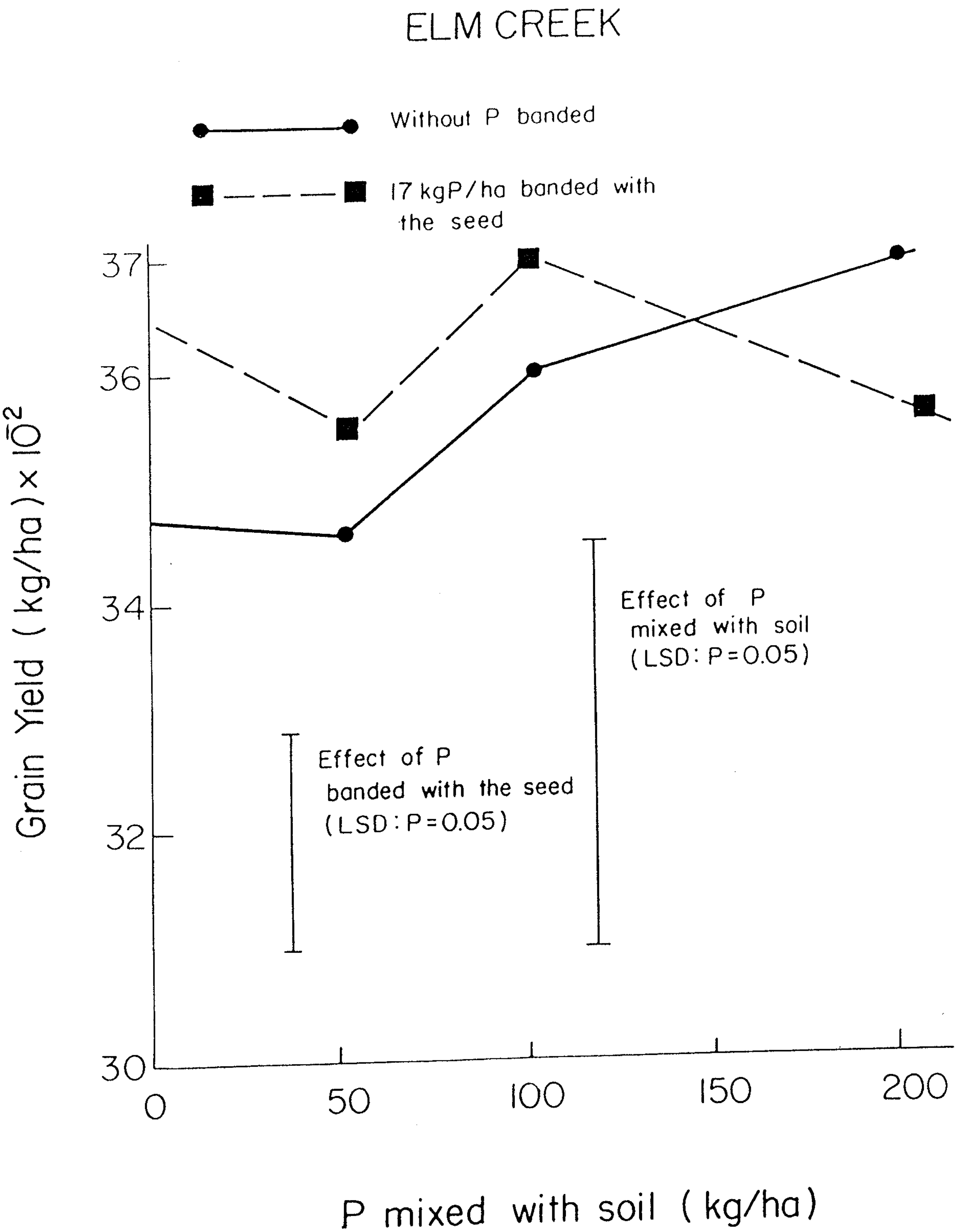


Figure 3: Influence of P Mixed with Soil Prior to Seeding and P Banded with the Seed on Grain Yield

matter yield due to amounts of P greater than those above was not significant.

The effect of P broadcast and P banded with the seed on P concentrations in shoots and total P uptakes were examined to see if they could explain the above observations. The trends for P concentrations in shoots and total P uptakes at the boot and heading stages of growth indicated an increase when P was broadcast and incorporated into soil prior to seeding compared to the check plants. The differences in P concentrations and uptakes due to 50 kgP/ha or greater were very small (Table 31). At the milk stage, the increase in P concentration and uptake due to P broadcast was apparent when 100 kgP/ha or more was incorporated into soil. At the early tillering stage (Table 31) the difference in P concentration as well as P uptake due to P broadcast was small probably because of low demand for P by the crop. The increase in P concentration as well as P uptake due to P broadcast indicated that P availability to the plants was increased by P broadcast. This may partly explain the dry matter yield responses to P broadcast and incorporated into soil prior to seeding.

P banded with the seed increased [P] in shoots and uptake only at the boot, heading and milk stages of growth. However, even at these growth stages the [P] and uptakes were increased by banded P only when no P was incorporated into soil prior to seeding, indicating that banded P had no effect on [P] and uptakes when P was broadcast to soil. The increases in [P] and uptake in this case was only a response to added P compared to the check. However, such increase in [P] did not result in a significant dry matter yield increase. The lack of dry matter yield increase could not be accounted for. At early tillering, the differences in P concentration and uptake due to banded P was smaller regardless of the quantity of P which was incorporated into soil prior to seeding also probably because of low demand for P by the crop.

The dry matter yield response to P broadcast observed at the three mid-stages of growth was not however, reflected in dry matter increase of the mature crop nor was it reflected in the grain yield. The examination of shoot P contents for example at the boot and heading stages of growth (Table 31) indicated that P was in the sufficiency range even in the check plants. The 0.36% P in shoot recorded at the boot stage was above the 0.30% P critical value suggested by Melsted et al. (1969) at a similar stage. Ward et al. (1973) suggested that P sufficiency level for wheat at heading was between 0.2-0.5% P. The value of 0.21% P recorded for the check plants at the heading stage was within the sufficiency range. The above suggests that probably P was not the most limiting factor for growth. It is likely that the dry matter yield response to P broadcast was the result of increased numbers of tillers in response to P above what was obtained in the check plots. Some might have died before maturity due to lack of other factors.

Copper concentrations in shoots and uptakes were little affected by either the rates of P broadcast, or by P banded with the seed throughout the growing period. According to the shoot Cu concentrations (Table 32), copper did not seem to be limiting. At the boot stage for example, the values of 3.7 to 5.3 ppm Cu in shoots were well above the 3.3 ppm Cu considered by Gupta and McLeod (1970) to be the optimum for wheat at that stage of growth and above the deficiencies level of 3.0 ppm Cu

Table 31: P Concentration and Uptake As Influenced by Amount of P Mixed with Soil and P Banded with the Seed (Elm Creek)

Stage of Growth	P Banded kg/ha	P Mixed with Soil (kg/ha)			
		0	50	100	200
				P*	
Early Tillering	0	0.50(.74)	0.48(.83)	0.58(1.0)	0.66(1.1)
	17	0.43(.74)	0.51(.84)	0.59(1.1)	0.67(1.3)
Boot	0	0.36(3.5)	0.45(6.1)	0.46(6.2)	0.55(7.3)
	17	0.49(4.5)	0.49(6.1)	0.52(7.4)	0.56(7.9)
Heading	0	0.21(7.3)	0.27(11.0)	0.31(11.9)	0.30(11.6)
	17	0.26(9.4)	0.31(11.9)	0.31(12.2)	0.36(14.2)
Milk	0	0.19(16.8)	0.19(17.8)	0.20(19.6)	0.22(21.7)
	17	0.21(20.0)	0.18(17.1)	0.19(19.2)	0.21(21.4)
Grain	0	0.45(15.9)	0.45(15.5)	0.45(16.1)	0.47(16.9)
	17	0.44(16.2)	0.44(15.7)	0.45(17.3)	0.44(15.5)
Straw	0	0.04(2.2)	0.05(2.6)	0.05(2.8)	0.07(4.1)
	17	0.04(2.4)	0.05(2.8)	0.05(3.0)	0.07(3.9)

* Numbers in brackets = P uptake (kg/ha)
Numbers outside the brackets = P Conc. (% P)

Table 32: Cu Concentration and Uptake As Influenced by Amount of P Mixed with Soil and P Banded with the Seed (Elm Creek)

Stage of Growth	P Banded kg/ha	P Mixed with Soil (kg/ha)			
		0	50	100	200
				Cu*	
Early Tillering	0	6.0 (0.89)	5.2 (0.9)	6.4 (1.1)	6.3 (1.2)
	17	5.8 (1.0)	5.9 (0.9)	6.5 (1.2)	6.2 (1.2)
Boot	0	4.4 (4.3)	5.2 (7.1)	3.7 (5.1)	5.3 (7.2)
	17	4.6 (4.4)	4.8 (6.0)	4.2 (6.0)	4.4 (6.3)
Heading	0	3.7 (13.0)	3.4 (13.8)	3.0 (11.6)	3.2 (12.3)
	17	3.8 (14.0)	3.7 (14.4)	4.2 (16.6)	4.7 (18.6)
Milk	0	3.1 (27.5)	3.2 (30.0)	3.0 (29.5)	2.7 (26.6)
	17	3.0 (28.6)	3.5 (33.3)	3.0 (30.3)	3.0 (30.6)
Grain	0	3.2 (11.2)	3.4 (11.6)	3.0 (10.7)	3.0 (11.0)
	17	3.4 (12.1)	3.4 (11.7)	3.1 (11.6)	2.8 (10.3)
Straw	0	2.5 (13.9)	2.8 (15.1)	3.1 (17.9)	2.8 (16.9)
	17	2.6 (15.6)	2.2 (12.8)	2.0 (12.1)	1.9 (10.0)

* Numbers in brackets = Cu Uptake (g/ha)
Numbers outside the brackets = Cu Conc. (ppm)

suggested by McAndrew (1979). At heading, shoot Cu concentrations were all above 3.0 ppm. Reliable literature regarding the critical level for Cu at this stage could not be found. It was felt that the critical value of 5.0 ppm Cu suggested by Ward et al. (1973) was rather too high according to this study because no visual Cu deficiency symptoms were seen and grain yields were generally good despite that copper concentration values in shoot were less than 5.0 ppm.

Generally zinc concentrations and uptakes were not affected by P broadcast or by P banded with the seed throughout the growing period (Table 33). The zinc contents in shoots as determined at the boot and heading stages were well above the 15 ppm suggested by Melsted et al. (1969) and Ward et al. (1973) respectively, as being critical.

Potassium and nitrogen were added to the soil in large quantities prior to seeding. Also sufficient quantities of these nutrients were taken up by the plants as evident from shoot N and K concentrations (Table 34). At the heading stage for example, N and K were above the sufficiency levels indicated by Ward et al. (1973). These researchers indicated that wheat was K deficient if tissue concentrations at the heading stage were less than 1.25% K. The same researchers also indicated N sufficiency level in spring wheat, at head emergence as 2.0% N.

Melsted et al. (1969) listed the Fe and Mn critical levels for wheat at boot stage as 25 ppm and 30 ppm respectively. The Fe and Mn values in this study as determined at the boot stage (Table 34) indicated that adequate amounts were present in all treatments.

Table 33: Zinc Concentration and Uptake As Influenced by Amount of P Mixed with Soil and P Banded with the Seed (Elm Creek)

Stage of Growth	P Banded kg/ha	P Mixed with Soil (kg/ha)			
		0	50	100	200
			Zn*		
Early Tillering	0	45 (6.6)	43 (7.3)	47 (7.9)	44 (7.8)
	17	45 (7.8)	37 (6.1)	40 (7.6)	41 (7.8)
Boot	0	31 (29.6)	31 (41.6)	35 (47.0)	30 (40.0)
	17	37 (34.1)	30 (37.1)	31 (43.5)	32 (44.9)
Heading	0	22 (76.4)	21 (76.8)	20 (78.0)	22 (83.0)
	17	23 (82.0)	21 (83.0)	21 (80.5)	20 (81.0)
Milk	0	13 (115.0)	11 (103.4)	11 (108.0)	11(108.5)
	17	12 (113.5)	9 (86.0)	9 (91.0)	10(101.9)
Grain	0	38 (133.0)	29 (100.0)	26 (93.0)	25 (92.0)
	17	34 (124.0)	27 (96.0)	26 (97.0)	25 (89.0)
Straw	0	6.6 (36.0)	4.6 (24.0)	4.3 (24.6)	3.7(22.0)
	17	5.7 (33.9)	5.0 (28.0)	4.7 (28.6)	4.2(23.0)

* Numbers in brackets = Zn Uptake (g/ha)
Numbers outside brackets = Zn Conc. (ppm)

Table 34: Nitrogen, K, Mn and Fe Concentrations and Uptake As Influenced by Amount of P Mixed with Soil and P Banded with the Seed (Elm Creek)

Stage of Growth	P Banded kg/ha	P Mixed with Soil (kg/ha)			
		0	50	100	200
			%N		
Boot	0	4.7	4.8	4.7	4.6
	17	5.1	4.9	5.0	4.8
Heading	0	2.4	2.5	2.4	2.6
	17	2.7	2.7	2.7	2.6
Grain	0	3.0	3.1	3.0	3.1
	17	3.1	2.9	3.0	3.1
			%K		
Heading	0	2.3	2.2	2.4	2.3
	17	2.2	2.4	2.1	2.6
			Mn(ppm)		
Boot	0	29.9	29.0	33.1	29.0
	17	29.7	31.9	30.0	32.0
			Fe(ppm)		
Boot	0	81	90	98	95
	17	110	103	114	101

Winkler

The dry matter yield was not significantly affected by the depth of P incorporation nor by the amount of P broadcast and incorporated into soil prior to seeding for any stage of growth (Tables 35 to 39). However, the 17 kgP/ha banded with the seed in soil into which 0, 50, 100 and 200 kgP/ha was incorporated prior to seeding increased dry matter yield significantly at all stages of growth except at the boot and milk stages (Tables 35a, 37a, 39a and Tables 36 and 38). Since the depth of P incorporation had no significant effect on dry matter yield, the means in Tables 35a, 37a and 39a are made up of eight observations.

The depth of P incorporation did not affect grain yield significantly either (Table 40) and therefore the means in Tables 40a are also made up of eight observations. The 17 kgP/ha banded with the seed in soil increased grain yield significantly at all levels of broadcast P (Table 40a). There was a declining trend in grain yield as the amounts of P broadcast were increased. The decrease, however, was significant only at the 200 kgP/ha rate (Table 40a, Fig. 4).

The trends of P concentrations in shoots at heading stage indicated an increase when P was banded with the seed regardless of the amounts of P broadcast. Total P uptake at this stage also showed a similar trend (Table 41). During early tillering, the difference in P concentration as well as total P uptake was small due probably to the low demand for P by the crop. For the rest of the sampling stages, the differences in P concentrations and uptakes due to banded P were not obvious and the reason for this is unclear (Table 41). The fact that both P concentration and uptake were increased by banded P at boot stage at least showed

Table 35: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Early Tillering (Winkler)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded With the Seed (kg/ha) 0	17
		Dry Matter Yield	
0 - 7.5	0	215	237
	50	260	238
	100	230	273
	200	242	245
0 - 15	0	194	244
	50	202	268
	100	224	269
	200	187	250

P Mixed with Soil: N.S.
P Banded with Seed: Significant P = 0.05
Depth of P Mixing: N.S.

Table 35a: Influence of P Banded with the Seed on Dry Matter Yield for One Level of P Mixed with Soil Over Two Depths of P Mixing - Early Tillering (Winkler)

P Mixed (kg/ha)	P Banded with the Seed (kg/ha) 0	17
	Dry Matter Yield (kg/ha)	
0	204 a	241 b
50	232 a	253 b
100	228 a	270 b
200	214 a	247 b

Means with the same letter in each row are not significantly different at 5% Tukey's Studentized Range.

Table 36: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Boot Stage (Winkler)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded With the Seed (kg/ha) 0	17
		Dry Matter Yield (kg/ha)	
0 - 7.5	0	1392	1583
	50	1517	1370
	100	1716	1697
	200	1687	1560
0 - 15	0	1282	1557
	50	1528	1687
	100	1560	1614
	200	1394	1440

None of the treatments affected dry matter yield significantly.

Table 37: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Heading Stage (Winkler)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded With the Seed (kg/ha) 0	17
		Dry Matter Yield	
0 - 7.5	0	4466	4940
	50	4932	5380
	100	4580	4582
	200	4783	5334
0 - 15	0	4714	5145
	50	4789	5384
	100	4498	5485
	200	4916	5413

Depth of P Mixing: N.S.
P Mixed with Soil: N.S.
P Banded with Seed: Significant P = 0.01

Table 37a: Influence of P Banded with the Seed on Dry Matter Yield for One Level of P Mixed with Soil Over Two Depths of P Mixing - Heading Stage (Winkler)

P Mixed (kg/ha)	P Banded with the Seed (kg/ha)	
	0	17
	Dry Matter Yield (kg/ha)	
0	4590 a	5043 b
50	4860 a	5382 b
100	4539 a	5033 b
200	4849 a	5373 b

Means with the same letter in each row are not significantly different at 5% Tukey's Studentized Range.

Table 38: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - Milk Stage (Winkler)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded With the Seed (kg/ha)	
		0	17
		Dry Matter Yield (kg/ha)	
0 - 7.5	0	9286	10120
	50	10145	10280
	100	9655	10337
	200	10102	10172
0 - 15	0	10072	10777
	50	10152	10650
	100	9740	9940
	200	9710	10040

None of the treatments affected dry matter yield significantly.

Table 39: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Dry Matter Yield (kg/ha) - At Maturity (Winkler)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded with the Seed (kg/ha) 0	17
		Dry Matter Yield	
0 - 7.5	0	8705	10060
	50	8610	9262
	100	8420	9202
	200	8105	9322
0 - 15	0	8493	9382
	50	8760	9437
	100	8825	9407
	200	8125	9125

Depth of P Mixing: N.S.
P Mixed with Soil: N.S.
P Banded with the Seed: Significant P = 0.05

Table 39a: Influence of P Banded with the Seed on Dry Matter Yield for One Level of P Mixed with Soil Over Two Depths of P Mixing - At Maturity (Winkler)

P Mixed (kg/ha)	P Banded with the Seed (kg/ha) 0	17
	Dry Matter Yield (kg/ha)	
0	8598 a	9721 b
50	8685 a	9349 b
100	8627 a	9305 b
200	8115 a	9223 b

Means with the same letter in each row are not significantly different at 5% Tukey's Studentized Range.

Table 40: Influence of Amount of P Mixed with Soil, Depth of P Mixing and P Banded with the Seed on Grain Yield (kg/ha) (Winkler)

Depth of P Mixing (cm)	P Mixed with Soil (kg/ha)	P Banded with the Seed (kg/ha)	
		0	17
		Grain Yield	
0 - 7.5	0	2852	3120
	50	2602	3055
	100	2435	2722
	200	2190	2590
0 - 15	0	2500	2930
	50	2645	2782
	100	2617	2925
	200	2315	2617

Depth of P Mixing:	N.S.
P Mixed with Soil:	Significant P = 0.05
P Banded with the Seed:	Significant P = 0.01

Table 40a: Influence of Amount of P Mixed with Soil and P Banded with the Seed on Grain Yield Over Two Depths of P Mixing (Winkler)

P Mixed (kg/ha)	P Banded with the Seed (kg/ha)	
	0*	17
	Grain Yield (kg/ha)	
0	2676 B a	3025 b
50	2633 B a	2918 b
100	2526 AB a	2823 b
200	2252 A a	2603 b

Means with the same small letter in each row are not significantly different at 5% Tukey's Studentized Range.

Means with the same capital letter in this column are not significantly different at 5% Tukey's Studentized Range.

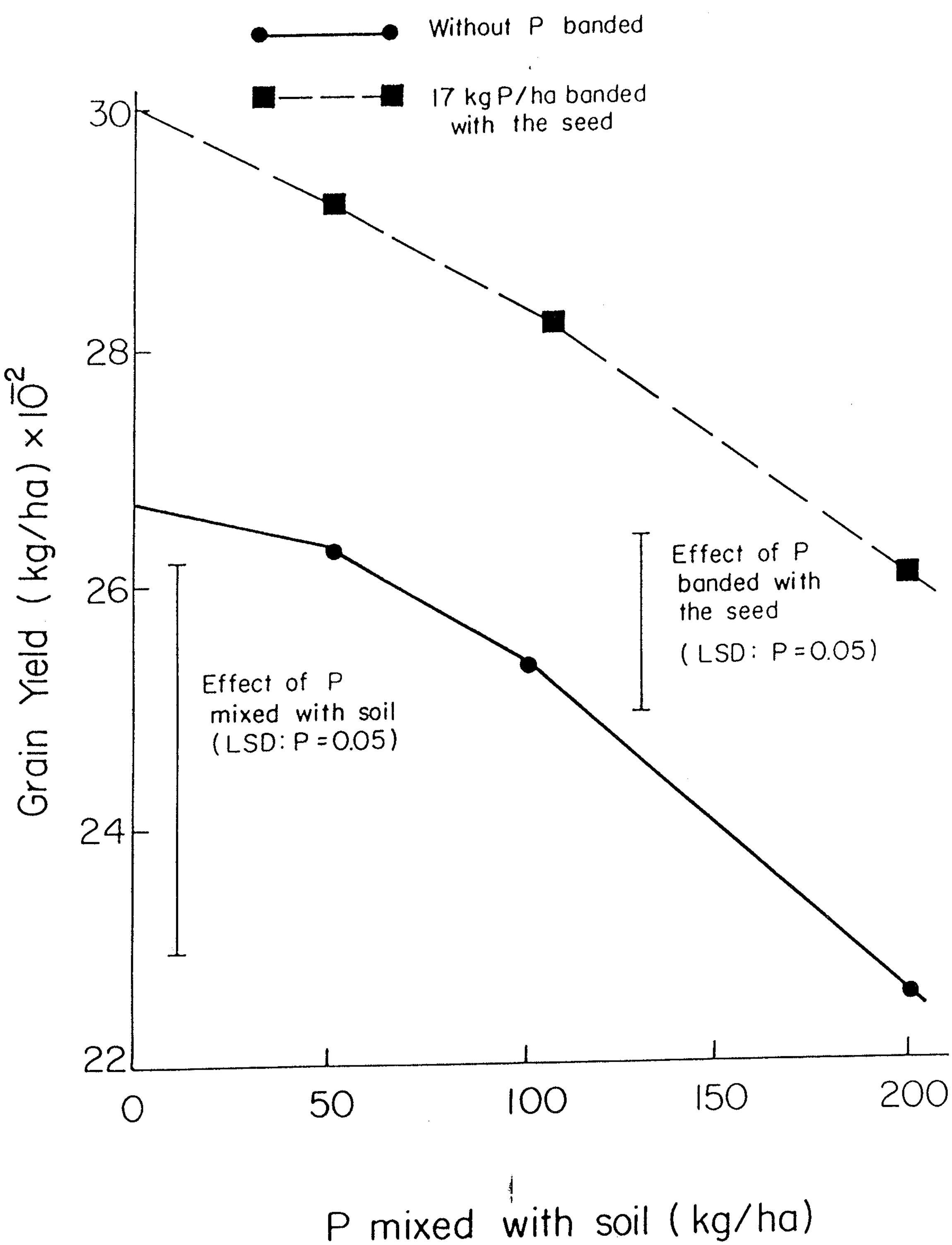


Figure 4: Influence of P Mixed with Soil Prior to Seeding and P Banded with the Seed on Grain Yield

that P in the band was more available than P mixed with soil. This may explain the dry matter and grain yield response to banded P at this site. The P concentration and uptake due to different rates of P broadcast and incorporated into soil prior to seeding showed one obvious trend. The P concentrations and uptakes were higher when P was added to soil than when no P was added. But the differences in P concentrations and uptakes due to different rates of P were very small at early stages of growth and did not show any consistent trend at later stages of growth (Table 41). This would suggest that the availability of P mixed with soil to the plants was about the same at 50 kg rate and beyond. This may partly explain the lack of significant dry matter response between various rates of P but failed to account for the lack of dry matter yield response betwen the 0-P rate and the rest.

The declining trend of grain yield as the amount of P broadcast and incorporated into soil increased was difficult to account for because no sign of seed and seedling injuries was evident from the dry matter yield response at early stages of growth. Secondly, most of the nutrients which were examined in this study were in sufficient quantities (Table 42). Ward et al. (1973) indicated sufficiency values of 2-3% N and 1.5-3% K for wheat at heading stage. All nitrogen values in this study were close to 3%. The K values were within the sufficiency range. Iron and manganese concentrations were far above the critical value of 25 ppm and 30 ppm respectively indicated by Melsted et al. (1969). Zinc concentrations in shoots (Table 43) were also above the 15 ppm critical levels (Melsted et al., 1969; Ward et al., 1973). Shoot Cu-concentrations at boot stage (Table 44) were marginal according to Melsted et al. (1969)

Table 41: P Concentration and Uptake As Influenced by Amount of P Mixed with Soil and P Banded with the Seed (Winkler)

Stage of Growth	P Banded kg/ha	P Mixed with Soil (kg/ha)			
		0	50	100	200
				P*	
Early Tillering	0	0.56(1.1)	0.60(1.4)	0.61(1.4)	0.65(1.4)
	17	0.59(1.4)	0.59(1.5)	0.62(1.6)	0.60(1.5)
Boot	0	0.36(4.8)	0.48(7.3)	0.52(8.5)	0.52(8.0)
	17	0.40(6.3)	0.48(7.3)	0.52(8.6)	0.53(8.0)
Heading	0	0.22(10.0)	0.34(16.5)	0.31(14.1)	0.35(16.9)
	17	0.26(13.1)	0.36(19.4)	0.34(17.1)	0.40(21.4)
Milk	0	0.15(14.5)	0.20(20.3)	0.27(26.0)	0.26(26.0)
	17	0.20(20.9)	0.20(20.9)	0.23(23.3)	0.28(28.3)
Grain	0	0.33(9.9)	0.37(9.7)	0.37(9.3)	0.44(9.9)
	17	0.36(10.9)	0.43(12.5)	0.40(11.3)	0.39(10.2)
Straw	0	0.12(7.1)	0.11(6.8)	0.09(5.5)	0.08(4.7)
	17	0.06(4.0)	0.08(5.4)	0.10(6.4)	0.10(6.5)

* Numbers in brackets = P uptake (kg/ha)
Numbers outside the brackets = Tissue Conc. (% P)

Table 42: Nitrogen, K, Mn and Fe Concentrations As Influenced by the Amount of P Mixed with Soil and P Banded with the Seed (Winkler)

Stage of Growth	P Banded (kg/ha)	P Mixed with Soil (kg/ha)			
		0	50	100	200
			%N		
Heading	0	2.6	2.6	2.7	2.7
	17	2.7	2.6	2.8	2.7
Grain	0	3.3	3.4	3.3	3.4
	17	3.3	3.3	3.2	3.3
			%K		
Heading	0	2.5	2.3	2.3	2.4
	17	2.3	2.5	2.3	2.1
			Mn(ppm)		
Boot	0	54	69	64	67
	17	68	67	61	68
			Fe(ppm)		
Boot	0	123	135	139	131
	17	120	138	126	128

Table 43: Zinc Concentration and Uptake As Influenced by the Amount of P Mixed with Soil and P Banded with the Seed (Winkler)

Stage of Growth	P Banded (kg/ha)	P Mixed with Soil (kg/ha)			
		0	50	100	200
				Zn*	
Early Tillering	0	40 (8.1)	41 (9.5)	41 (9.3)	43 (9.2)
	17	45 (10.8)	42 (10.6)	44 (11.8)	42 (10.4)
Boot	0	24 (32.0)	27 (41.0)	28 (45.8)	31 (47.7)
	17	31 (48.6)	34 (51.9)	26 (43.0)	30 (45.0)
Heading	0	18 (83.0)	17 (83.0)	18 (82.0)	19 (90.0)
	17	15 (75.0)	19 (103.0)	18 (89.0)	15 (81.0)
Milk	0	12 (116.0)	13 (132.0)	10 (97.0)	10 (98.0)
	17	10 (104.0)	10 (105.0)	10 (103.0)	10 (101.0)
Grain	0	36 (97.0)	32 (83.0)	27 (68.0)	26 (58.0)
	17	28 (85.0)	27 (77.0)	25 (71.0)	23 (60.0)
Straw	0	7 (40.0)	4 (26.0)	4 (26.0)	5 (27.0)
	17	5 (32.0)	5 (33.0)	4 (29.0)	4 (28.0)

* Numbers in brackets = Zn uptake (g/ha)
Numbers outside the brackets = Zn Conc. (ppm)

Table 44: Cu Concentration and Uptake As Influenced by the Amount of P Mixed with Soil and P Banded with the Seed (Winkler)

Stage of Growth	P Banded (kg/ha)	P Mixed with Soil (kg/ha)			
		0	50	100	200
				Cu*	
Early Tillering	0	7.5 (1.6)	8.1 (1.9)	7.4 (1.7)	7.9 (1.7)
	17	7.0 (1.7)	6.7 (1.7)	8.1 (2.2)	7.6 (1.9)
Boot	0	4.1 (5.7)	4.2 (6.5)	4.4 (7.3)	4.7 (7.3)
	17	4.7 (7.5)	5.1 (7.9)	3.2 (5.4)	4.1 (6.2)
Heading	0	3.7 (16.6)	3.5 (17.0)	3.4 (15.2)	3.1 (14.8)
	17	3.6 (18.3)	3.6 (19.5)	3.6 (18.4)	3.5 (18.9)
Milk	0	3.3 (32.4)	3.2 (32.9)	3.1 (30.3)	2.8 (28.5)
	17	2.5 (26.0)	2.3 (24.1)	2.5 (25.6)	2.8 (28.7)
Grain	0	3.5 (9.4)	3.3 (8.6)	2.5 (6.3)	2.5 (6.1)
	17	2.5 (7.6)	3.1 (9.1)	2.6 (7.3)	2.6 (6.6)
Straw	0	1.2 (7.4)	1.6 (13.3)	1.7 (10.6)	2.1 (12.5)
	17	1.6 (11.0)	1.8 (11.9)	1.7 (11.5)	1.8 (12.0)

* Numbers in brackets = Cu uptake (g/ha)
Numbers outside the brackets = Cu Conc. (ppm)

but they were above the optimum level of 3.3 ppm Cu suggested by Gupta and McLeod (1970) and above the deficiency level of 3.0 ppm suggested by McAndrew (1979) at the same stages of growth. The severe lodging at this site at heading stage could partly account for the low harvest index (Table 19) recorded at this site compared to Elm Creek site, probably by affecting the light interception in the crop (Fisher and Wilson, 1975). The declining trends of grain yield oberved as the level of broadcast P increased could not be explained by lodging as this was almost uniform over all treatments.

P concentrations and P uptake by plants were not influenced by the depth of P incorporation for any stage during the entire growing period (Table 45). This helps to explain the lack of response to depth of P incorporation.

Table 45: P Uptake and Concentration As Influenced by the Depth of P Incorporation

Stage of Growth	Depth of P Incorp. (cm)	P Mixed with Soil (kg/ha)			
		0	50	100	200
Early Tillering	0 - 7.5	0.54(1.2)	0.60(1.6)	0.62(1.4)	0.65(1.6)
	0 - 15	0.57(1.1)	0.64(1.3)	0.60(1.3)	0.61(1.1)
Boot	0 - 7.5	0.35(4.9)	0.50(7.6)	0.46(7.9)	0.53(8.9)
	0 - 15	0.37(4.7)	0.46(7.0)	0.52(8.1)	0.51(7.1)
Heading	0 - 7.5	0.22(9.8)	0.37(18.2)	0.31(14.2)	0.35(16.7)
	0 - 15	0.21(9.8)	0.31(14.8)	0.30(13.5)	0.34(16.7)
Milk	0 - 7.5	0.16(14.9)	0.22(22.3)	0.26(25.1)	0.25(25.3)
	0 - 15	0.14(14.1)	0.19(19.3)	0.26(25.3)	0.26(25.2)

Note:

Numbers in brackets = P Uptake (kg/ha)
Numbers outside the brackets = P Conc. (% P)

Chapter 6

STUDY 3: LYSIMETER EXPERIMENT

Introduction

In the first growth chamber experiment it was found that the effect of P incorporated into 0-15 cm and 15-30 cm depths on phosphorus derived from fertilizer or dry matter yields were not only significantly different at each soil moisture regime.

An experiment to evaluate the effect of shallowly incorporated P and deeply incorporated P on yield responses under field conditions was conducted in the field using lysimeters. Attention was paid to the effect of P additions and depth of P incorporation on dry matter and grain yield.

Materials and Methods

The experiment was conducted adjacent to the large field experiment at the Haywood site discussed in Chapter 4. A randomized complete block design was used with four replications. Open end iron cylinders (lysimeters) which were 25 cm in depth and had a cross-sectional area of 0.99 m^2 were arranged evenly and pressed into the ground to the depth of about 20 cm. The lysimeters were placed 35 cm apart between replicates and 63 cm apart within replicates. Soil was dug out of each lysimeter from the appropriate depth leaving the soil below it undisturbed. For 15-30 cm P incorporation, soil from 0-15 cm layer was dug out first and put on a separate paper. The soils were mixed thoroughly with fertilizer P on a plastic paper. Appropriate amounts of P (DCPD) granules were crushed in a mortar then mixed with a small amount of dry soil. The mixture was then mixed with a small portion of soil to which P had to be added. The mixture was then mixed with some more soil and repeated until the P was mixed with the entire volume of soil. The soil and added P was then returned to the lysimeter into the appropriate depth. Treatments are shown in Table 46. In addition to P the equivalent of 200 kgK/ha (KCl) and 150 kgN/ha (NH_4NO_3) were also applied to all treatments. These were mixed with soil in the 0 to 7.5 cm layer the same way P was added. About 23 seeds (equivalent of 100 kg/ha) of wheat (*Triticum estium* var. Columbus) were planted in each lysimeter. The seed were planted into about 23, 2.5 cm deep holes which were evenly spaced on the soil surface in each lysimeter. The area between the lysimeters and an area extending about 1.0 m outside the outer lysimeters was also seeded with the same variety using a hand driven one-row seed drill. This area was fertilized with blanket quantities of N, P and K prior to seeding. The fertilizers, NH_4NO_3, DCPD and KCl were carefully hand broadcast in this area and mixed in with a hand hoe. Planting was done on the 1st of June, 1982. Germination and emergence were good. The mature plants from each lysimeter were harvested just above the soil surface. The number of tillers with fertile heads for each lysimeter were counted. The samples were air dried and total dry matter yield determined. Samples were then hand threshed and the clean grain weight determined. Also 100 kernel weight for each lysimeter was determined. Grain and straw samples were ground for P analysis.

Table 46: Treatment Structure for Lysimeter Experiment

Treatment No.	P-mixed with Soil (kg/ha)	Depth of P-mixing (cm)
1	0	-
2	50	0 - 7.5
3	50	0 - 15
4	50	0 - 30
5	50	15 - 30
6	100	0 - 7.5
7	100	0 - 15
8	100	0 - 30
9	100	15 - 30

RESULTS AND DISCUSSION

There was a significant increase in dry matter yield due to P added to soil. The 100 kgP/ha rate did not result in a significant dry matter yield difference from that obtained with the 50 kgP/ha rate.

The dry matter yield was also influenced by the depth of P incorporation (Table 47). Phosphorus incorporated into the 0-7.5 cm and 0-15 cm layers resulted in a significantly higher yield than when it was incorporated into the 0-30 cm or 15-30 cm layers of soil. The dry matter yields due to P incorporated into 0-7.5 cm and 0-15 cm was not significantly different. Also the dry matter yields due to P incorporated into 0-30 cm and 15-30 cm were not significantly different from each other.

In general, grain yields (Table 47) were similar to the total dry matter yields. Yield was significantly increased by the 50 kgP/ha rate. The application of 100 kgP/ha did not result in a significant grain yield difference from that obtained with the 50 kgP/ha rate. Phosphorous incorporated into 0-7.5 cm and 0-15 cm depths resulted in a significantly higher grain yield than when P was incorporated into either 0-30 cm or 15-30 cm of soil layers. The yields due to P incorporated into 0-7.5 and 0-15 cm of soil layers were not significantly different. Also, the yields due to 0-30 cm and 15-30 cm P incorporation were not significantly different.

The response to P fertilizer was expected as the soil was deficient in P. The 6.0 kgP/ha $NaHCO_3$ extractable P is considered very low (Leitch et. al., 1980). However, the lack of a significant dry matter

Table 47: Effect of P Mixed with Soil and Depth of P Mixing on Dry Matter Yield and Grain Yield

Treat	P Mixed With Soil (kg/ha)	Depth of P Mixing (cm)	Yield (kg/ha)	
			Dry Matter	Grain
1	0	-	4120 a	1100 a
2	50	0 - 7.5	9510 c	3440 c
3	50	0 - 15	9520 c	3870 c
4	50	0 - 30	6010 b	2160 b
5	50	15 - 30	6080 b	2250 b
6	100	0 - 7.5	9440 c	3210 c
7	100	0 - 15	8830 c	2920 c
8	100	0 - 30	6996 b	2470 b
9	100	15 - 30	5790 b	2500 b

Means with the same letter in each column are not significantly different at 5% Tukey's Studentized Range.

or grain yield difference between 50 kgP/ha and 100 kgP/ha tended to suggest that in this particular experiment 50 kgP/ha was adequate.

The higher yields obtained by shallow incorporation of P (0-7.5 and 0-15 cm) than deep incorporation (15-30) or mixing P with the entire volume of soil in the lysimeter was attributed to a large extent to increased number of tillers in the former case as observed at maturity (Table 48). The weight (size) of individual grain had a negligible effect (Table 48). The differences in the number of tillers was most likely due to differences in P availability to the plants during the early stages of growth when P was shallowly incorporated than incorporated into 15-30 cm depth. The shallow incorporated P likely was readily accessible to plants during the early stages of growth. Some time had to elapse before roots could penetrate and utilize P placed 15-30 cm

Table 48: Effect of P Mixed with Soil and Depth of P Mixing on Numbers of Tillers with Heads/Lysimeter and 100 Kernel Weight

Treat	P Mixed With Soil (kg/ha)	Depth of P Mixing (cm)	#'s of Tillers/ Lysimeter	100 Kernel Weight (g)
1	0	-	27 a	2.94 a
2	50	0 - 7.5	58 c	3.02 a
3	50	0 - 15	55 c	3.18 a
4	50	0 - 30	38 b	2.95 a
5	50	15 - 30	41 b	3.00 a
6	100	0 - 7.5	56 c	3.18 a
7	100	0 - 15	55 c	2.91 a
8	100	0 - 30	43 b	2.87 a
9	100	15 - 30	38 b	2.28 a

Means with the same letter in each column are not significantly different at 5% Tukey's Studentized Range.

deep. At a later stage, P placed deep was also available to the plants as the total P uptake at maturity was about the same regardless of depth of P incorporation with the exception of the check treatment where the uptake was very low (Table 49). The effect of deep fertilization on yield was consistent with that made by Larson et al. (1960) with corn and oats, Phillips and Norman (1967) for sorghum. Their results showed that deep fertilization should be made with assurance of adequate surface fertilization to get advantage of deep fertilization.

The effect of P availability on the number of tillers could not explain the low numbers of tillers observed when 100 kgP/ha was incorporated into 0-30 cm because the concentrations of P in the 0-15 cm layers of soil were the same when 100 kgP/ha and 50 kgP/ha were incorporated into 0-30 cm and 0-15 cm depths respectively. It was felt that

Table 49: Trends of % P and Total P Uptake as Affected by P Mixed with Soil and Depth of P Mixing

Treat	P Mixed With Soil (kg/ha)	Depth of P Mixing (cm)	% P Grain	% P Straw	Total P Uptake (kg/ha)
1	0	-	0.30	0.038	4.6
2	50	0 - 7.5	0.35	0.032	14.3
3	50	0 - 15	0.35	0.035	14.6
4	50	0 - 30	0.39	0.048	10.4
5	50	15 - 30	0.39	0.050	10.7
6	100	0 - 7.5	0.40	0.048	12.1
7	100	0 - 15	0.37	0.047	14.2
8	100	0 - 30	0.37	0.075	12.0
9	100	15 - 30	0.39	0.053	11.5

the low numbers of tillers when 100 kgP/ha was incorporated into 0-30 cm was most likely due to factors other than P availability. For the 0-30 cm P mixing, the soil from the entire depth was mixed together. Some of the physical properties may have been altered in the process. However possible altered physical properties of soil in the profile could not fully explain the reduction in numbers of tillers and yields because no such reduction was observed for the K experiment adjacent to the P experiment when K was mixed with soil from the 0-30 cm depth.*

Grain copper and zinc contents were examined to see if the mixing of large amounts of P with large volumes of soil had any effect and if the observations could aid in explaining the low numbers of tillers and yields when 100 kgP/ha was mixed with soil from 0-30 cm.

* Pers. Communication with M. Maina - Dept. Soil Sci. (U. Manitoba)

Copper concentrations in grain were found to decline considerably when 100 kgP/ha was mixed with soil from 0-30 cm layer of soil (Table 50). The concentration of Cu in grain for example, dropped from 6.7 to 2.3 ppm when 100 kgP/ha was mixed with soil from 0-7.5 cm and 0-30 cm soil layers respectively. The 2.3 ppm Cu in grain is less than a critical concentration of 2.5 ppm for field grown wheat grain suggested by King and Alston (1975a) and close to the critical concentration of 2.0 ppm Cu suggested by Caldwell (1971) for field grown wheat grain. The sharp decline in grain [Cu] indicated that mixing large quantities of P with the large volume of soil had a bad effect on Cu uptake or translocation. Some literature (Graham and Nambriar, 1981) indicated that moderate Cu deficiency can result in excess late tillering and high mortality on the late tillers in wheat and it is possible that the low numbers of tillers with fertile heads observed in this study were due partly to the above. Zinc concentrations in grain also tended to decline when 100 kgP/ha was mixed with large volume of soil but, the decline was not so drastic as that observed for Cu.

The grain Cu concentration when 50 kgP/ha was mixed with soil from the 0-30 cm depth was not reduced appreciably compared with other depths of P incorporation. Zinc content in grain was not reduced drastically either by mixing 50 kgP/ha with soil for 0-30 cm depth. The dilution of P that occurred when 50 kgP/ha was mixed with the large volume of soil might have reduced the tillering capacity of the plants and hence low numbers of tillers and dry matter and grain yields observed for this treatment due to a lower amount of available P.

Table 50: Effect of P Mixed with Soil and Depth of P Mixing on Grain Cu and Zn Contents

P Mixed With Soil (kg/ha)	Depth of P Mixing (cm)	Grain [Cu] and [Zn] (ppm)	
		Cu	Zn
0	-	9.8	37.8
50	0 - 7.5	6.4	27.9
50	0 - 15	7.5	31.0
50	0 - 30	6.1	27.9
50	15 - 30	6.8	30.7
100	0 - 7.5	6.7	26.1
100	0 - 15	4.5	24.3
100	0 - 30	2.3	25.1
100	15 - 30	5.0	26.4

Results from the first growth chamber experiment showed that the dry matter yields due to P incorporated into 0-15 cm and 15-30 cm soil layers were not significantly different at both low and high soil moisture regimes. Results from the lysimeter however, showed yield decline when P was incorporated into 15-30 cm depth. Differences in soil temperatures and distribution of nutrients other than P in the soil profiles in the two experiments might have contributed in part to the differences observed for the depth of P incorporation. Soil temperatures in the growth chamber were relatively higher than the soil temperatures that are normally found in the field in early spring. Low soil temperatures might have restricted root growth to some extent in the deep layers of soil early in the season thereby limiting early utilization of P incorporated into 15-30 cm depth. In the growth chamber where soil temperatures were conducive for root growth, roots were probably able to grow into the 15-30 cm soil layer in a short period of time and thereby able to utilize P in the 15-30 cm soil layer.

In the growth chamber experiment nitrogen, which was also limiting as evident from very low values of NO_3-N, was evenly mixed with the whole soil in the pots. In the lysimeter experiment K which was also deficient in soil as evident from high yield responses to K was only applied to the 0-7.5 cm soil layer. Localized K in the lysimeter might have caused the localization of the roots into the shallow layers of soil, at least in the early stages of plant growth, thereby limiting early utilization of P in the 15-30 cm depth unlike the growth chamber experiment where nitrogen was evenly mixed with the entire soil in the pots.

Chapter 7

STUDY 4: SECOND GROWTH CHAMBER EXPERIMENT

Introduction

Field results from the Haywood site showed a dry matter and grain yield reponse to P additions but grain yield declined at the highest rate of P used. No similar decline in vegetative yield was observed at any stage during the growing period. It was felt that P induced copper deficiency might have affected grain formation thereby reducing the harvest index.

Shoot and grain Cu concentrations and uptakes at the Haywood site were generally lower for all treatments than those recorded at Elm Creek and Winkler sites indicating that Cu supplying capacity by the Haywood soil was lower than that of Elm Creek and Winkler sites and perhaps not adequate. It was felt that low values of Cu concentrations in shoots due to dilution might have been due to failure of the soil to supply sufficient copper Cu to meet the increased demand. A growth chamber experiment was thus conducted using the Haywood soil to study the influence of Cu additions on dry matter and grain yield response to phosphorus.

Materials and Methods

The soil was taken from the 0-15 cm depth in the fall of 1982 from the fallow land next to the field experimental plot at Haywood. The soil is the Almasippi Series mapped by Michalyna and Smith (1972) as

Gleyed Carbonated Rego Black soil. Some of the physical and chemical properties of the soil were described in Table 1 under the Haywood site. The soil was air-dried, sieved through a 2.0 mm sieve, mixed thoroughly and stored for later use.

The treatments consisted of five rates of P, 0, 25, 50, 100 and 200 ppm P as Cu $(H_2PO_4)_2 . H_2O$ and three rates of Cu, 0, 4 and 8 ppm $(CuCl_2.2H_2O)$ for each level of phosphorus. Phosphorus was first ground in a mortar and then mixed with a small portion of soil. The mixture was then mixed with another small portion of soil and repeated until all 6 kg soil per pot was mixed with P. Copper for appropriate treatments was dissolved in 200 ml of distilled water and then sprayed onto the soil spread on a plastic sheet to give a uniform coverage. Other nutrients 8 ppm Zn (Zn $SO_4.7H_2O$), 20 ppm S as Zn $SO_4.7H_2O$ and K_2SO_4, 100 ppm N (Urea) and 100 ppm K (K_2SO_4 and KCl) based on 6 x 45 kg soil were dissolved in 1000 ml of distilled water. From this, 22.2 ml aliquots were drawn and diluted to 1200 ml with distilled water. The resulting solutions were added to soil in pots 2 days before seeding. The above amounts of solutions were required to bring the soil in each pot to field capacity (20%).

Four weeks after seeding each pot received an additional application of 50 ppm N as urea. Each treatment was replicated three times in a completely randomized design. Seeding of wheat Triticum estivum var. Columbus was done on August 12, 1983 with emergence being observed about 5 days later. Pots were watered on a daily basis. The plants were thinned to six after 10 days. Conditions in the growth chamber were set as follows: temperature 15°C (night) and 25°C (day); day length 15 hours; humidity 80% (night) and 50% (day). The light intensity ranged from 500 to 550 microeinsteins m^{-2} sec^{-1}. Plants were harvested at maturity, 90 days after seeding just above the soil surface and dried in loosely closed paper bags at about 40°C for 7 days. The dry weights were determined. The samples were hand threshed and cleaned. The weights of grain were taken and the grain ground for laboratory analysis.

Results and Discussion

The dry matter yield increased significantly with an increase of P up to the 200 ppm rate, both with and without added copper. Copper additions tended to increase dry matter yields at higher rate of P, but the increases were not significant (Table 51).

Grain yields were increased by additions of P. At low and medium levels of P, grain yields were not influenced by copper additions. At higher P rates, copper additions increased grain yield significantly (Table 52). Phosphorus additions at the rates of 25 and 50 ppm P increased grain yield significantly both with and without added Cu, but a further yield increase at the rates of 100 and 200 ppm P only occurred when Cu was added to soil. The 8 ppm Cu addition was no better than 4 ppm Cu rate.

Grain copper content (Table 54) and harvest index (Table 53) were examined to see if they could aid in explaining at least some of the observations made above. When copper was not added to the soil, copper content in grain was generally low and declined considerably as the amount of P added to soil increased. The grain copper contents were

Table 51: Influence of P and Cu on Dry Matter Yield (g/pot)

Cu (ppm)	P (ppm)				
	0	25	50	100	200
0	20.6 a	43.3 b	47.6 c	51.3 de	55.5 fgh
4	18.2 a	44.1 b	49.9 cd	53.8 ef	57.5 gh
8	18.6 a	43.6 b	47.7 c	54.5 efg	58.4 h

Means with the same letter are not significantly different at 5% L.S.D.

Table 52: Influence of P and Cu on Grain Yield (g/pot)

Cu (ppm)	P (ppm)				
	0	25	50	100	200
0	7.4 a	16.1 b	18.9 c	19.5 c	20.6 c
4	6.8 a	16.5 b	19.0 c	23.2 d	26.0 e
8	6.5 a	16.7 b	19.1 c	23.6 d	26.2 e

Means with the same letter are not significantly different at 5% L.S.D.

Table 53: Influence of P and Cu on Harvest Index (%)

Cu (ppm)	P (ppm)				
	0	25	50	100	200
0	36 ab	37 ab	39 abcd	38 abc	37 ab
4	36 ab	38 abc	38 abc	44 de	45 e
8	35 a	38 abc	40 abcde	43 de	44 de

Means with the same letter are not significantly different at 5% L.S.D.

Table 54: Influence of P and Cu on Grain Copper Content

Cu (ppm)	P (ppm)				
	0	25	50	100	200
			Cu (ppm)		
0	3.8	1.8	1.1	0.6	0.6
4	5.0	3.9	3.9	2.8	3.0
8	5.4	4.6	4.3	3.9	3.5

below the critical concentration of 2.0 and 2.5 ppm Cu suggested by Caldwell (1971) and King and Alston (1975a) for wheat when P was added. Copper additions however, raised the grain copper concentration above the critical levels.

When copper was not added to soil, P addition did not increase the harvest index significantly. Similarly when no P was added to soil the addition of Cu had no significant influence on the harvest index. Also at low and medium rates of P the addition of Cu had no significant effect on harvest index. An increase in harvest index due to copper addition was observed when 100 and 200 ppm P were added to soil. Since the dry matter yields were not significantly affected by copper additions, the further increase in grain yield observed for the 100 and 200 ppm P rates when copper was added was mainly due to improved harvest index.

The decline in harvest index at higher rates of P observed in the field experiment at Haywood was not observed in the growth chamber experiment even when Cu was not added. This is despite the fact that the grain [Cu] were also below the critical concentration when P was added to the soil to which copper was not added. The reason for this is not well understood.

From the field experiment results at the Haywood site, it was felt that the decline in grain yield at the highest rates of P was probably due to P induced copper deficiency. Using the same Haywood soil, it was shown in the environment growth chamber experiment that P additions reduced the grain [Cu] below the critical level when copper was not added and grain yield did not respond well to P additions. Addition of

Cu however, raised the grain [Cu] above the critical level and grain yield responded well to all rates of P. This suggested that in order to obtain maximum yield of grain due to large P addition, copper supply should also be in large quantity.

Chapter 8

SUMMARY AND CONCLUSIONS

The quantity of P added to soil and methods of application are important if maximum yield of wheat is to be obtained. Environmental factors particularly soil moisture during the growing period can modify yield responses to P in a major way.

Field, growth chamber and lysimeter studies were conducted to evaluate the influence of P additions and various methods of P application on maximum yield of wheat.

The influence of soil moisture regimes and P additions on dry matter and Pdff was investigated in a growth chamber experiment. The effect of P additions and water supply on water use efficiency was also studied in the same experiment. The low soil moisture regime reduced yields and Pdff by about 50 percent but had no effect on shoot P concentrations. The Pdff increased with increase in P additions in both high and low soil moisture treatments, but a similar increase in dry matter yield was observed only in the high moisture treatment. It was concluded that low yields in the low moisture treatment was most likely due to a direct effect of moisture stress on the plant growth rather than a limited supply of P to the plants. Water use efficiency was increased by P additions in soil low in P but the amount of water supplied to the plants had no significant influence on water use efficiency.

At the Haywood and Elm Creek sites where the soils had low and medium levels of $NaHCO_3$ extractable P respectively, P broadcast increased dry matter yields significantly. Grain yields however, responded to P broadcast only at the Haywood site. Dry matter and grain yields at Haywood generally increased with increasing amount of P up to 100 kgP/ha. Beyond this rate dry matter yield remained constant, but grain yield declined. At the Winkler site where the soil had medium to high levels of $NaHCO_3$ extractable P, the dry matter yields did not respond to P broadcast. However, a negative response to rates of P was observed with the grain yields. The lodging of the plants that occurred at the heading stage of growth might have influenced grain yield results to some extent. The influence of P broadcast on [P] and uptakes for the three sites was examined. The [P] and uptakes tended to increase as the amount of P broadcast increased up to the 100 kgP/ha rate at Haywood. At Elm Creek there was an apparent increase in [P] and uptakes only at three mid-harvests and only when large amounts of P were added to soil. At the Winkler site [P] and uptakes were higher when P was added than when no P was added. But, the differences in [P] and uptakes due to different rates of P were very small at early stages of growth and inconsistent at later stages of growth.

Banding 17 kgP/ha with the seed in soil into which various amounts of P were incorporated prior to seeding increased dry matter and grain yield at Haywood and Winkler sites. The yields at the Haywood site were significantly increased by P banded with the seed only at low rates of P broadcast. At the higher rates of P, phosphorus banded with the seed accentuated grain yield decline. At the Elm Creek site dry matter and grain yields did not respond to banded P. At Winkler, dry matter and grain yields responded to banded P at all rates of broadcast P even though the general trend for grain yields were declining as the rates of broadcast P increased. At the Haywood site P banded with the seed generally increased P uptakes at all stages of growth when it was banded in soil into which low rates of P were incorporated prior to seeding. At Elm Creek the P banded with the seed increased [P] and uptakes only at three mid-harvests and only when no P was incorporated into soil prior to seeding. At the Winkler site, however, there was an increase of [P] and uptake due to banded P regardless of the amount of P incorporated into soil prior to seeding. It was generally concluded that maximum grain yield could be produced without P fertilizer addition in soils with medium to high levels of $NaHCO_3$ extractable P. In soils low in $NaHCO_3$ extractable P a considerable amount of P is required in order to obtain maximum yields. The amount of P required is much less if part of P is banded with the seed and part broadcast than when the broadcast and incorporation is the only mode of P application.

At all three sites, N, K, Zn, Fe and Mn were present in sufficient quantities for all treatments of P. At Elm Creek and Winkler, copper also did not seem to be limiting. At Haywood however, copper concentrations in the plants were marginal at the highest rates of P. Results from a Cu-P interaction study in the growth chamber with the Haywood soil also showed similar trends. Higher rates of P reduced grain [Cu] below the critical level when copper was not added. The grain yield increases due to higher rates of P were significantly higher than those obtained with lower rates of P only when copper was added. The above results suggest that heavy rates of P are not desirable in soils marginal in Cu as this may induce Cu-deficiency thereby affecting grain yield response to P.

The effect of depth of placement of P on yields and uptakes was studied in a growth chamber, lysimeters and field experiments. The results from the field and lysimeter experiments showed that the 0-7.5 cm and 0-15 cm depths of P incorporation were equally effective in terms of P availability to the plants. From the lysimeter experiment it was found that shallow (0-15 cm) placement of P was better than the 0-30 cm or 15-30 cm depths of P placement in terms of yield response. However, under a controlled environment in the growth chamber the effects of the 0-15 cm and 15-30 cm depths of P placement on yield were not significantly different. It was concluded that under field conditions the 0-7.5 cm and 0-15 cm depths of P placement are equally effective in yield response to P irrespective of soil P. The fact that in P deficient soil the shallow placement of P was superior to deep placement in increasing the yields emphasized the importance of having P near the seed for better yields.

Chapter 9

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Chapter 10

APPENDIX 1: Soil Moisture Content at Seeding and Harvesting

Depth (cm)	Soil Moisture Content (% Weight Basis)	
	At Seeding	At Harvest
	Haywood	
0 - 15	18.4	11.1
15 - 30	20.0	12.4
30 - 60	13.6	9.0
60 - 90	16.9	10.0
90 - 120	22.8	17.3
	Winkler	
0 - 15	25.9	12.2
15 - 30	25.3	12.7
30 - 60	23.7	13.3
60 - 90	24.0	13.9
90 - 120	31.0	22.6
	Elm Creek	
0 - 15	23.8	15.0
15 - 30	24.7	12.0
30 - 60	22.0	16.5
60 - 90	24.7	10.0
90 - 120	25.8	25.0

APPENDIX 2: Growing Season Rainfall (cm-rain)*

	Haywood	Winkler	Elm Creek
June 8 to June 29	4.24	6.77	4.19
July	6.13	4.95	7.73
August	2.38	4.63	2.42

* Rainfall measurements were made on site using the rain gauges installed at each experimental plot.

APPENDIX 3: Bulk Densities for Soils Used for the Field Experiment

Depth (cm)	Haywood	Winkler	Elm Creek
		B.D.*	
0 - 15	0.93	0.98	1.15
15 - 30	1.30	1.22	1.44
30 - 60	1.48	1.24	1.47
60 - 90	1.48	1.34	1.51
90 - 120	1.48	1.34	1.40

* Bulk densities were determined by the auger technique (Shaykewich, 1965).