EFFECTS OF SEED-BANDED AND PREPLANT-BANDED APPLICATIONS OF N AND P FERTILIZER ON WINTER WHEAT (*TRITICUM AESTIVUM* L.)

by

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INTRODUCTION

Preplant-banded applications of N and P fertilizer have been shown to be an effective method of fertilizer placement for winter wheat. These fertilizer applications produce uneven growth of wheat ("wavy effect") when band spacings wider than 25 cm are used in soils with low levels of available P. Under those conditions, plants growing directly over preplant bands show more vegetative growth and produce higher grain yields than plants growing between preplant bands. These observations suggest that a better nutrient supply could also be beneficial to plants growing between preplant bands. An increased nutrient supply to these plants could increase their growth and final grain yield resulting in an overall increase in grain yield. One method of improving the nutrient supply to plants growing between preplant bands is by banding fertilizer with the seed (seed-banded fertilizer) at planting time.

With this in mind, field studies were conducted during the 1980-81 and 1981-82 crop years with the following objective:

- To evaluate the effects of combinations of preplant-banded and seed-banded applications of N and P fertilizer on growth and grain yield of winter wheat.

Field observations raised questions about the effect root development in fertilizer bands has on nutrient absorption from other soil areas. Research has shown that extensive root growth occurs near N and P fertilizer bands. Fertilizer banded with the seed could result in extensive root growth near the seed band, in turn delaying root extension toward preplant bands placed deeper in the soil. Similarly, extensive root development near the preplant band could affect nutrient absorption from the seed-banded fertilizer.

In order to investigate these aspects, a greenhouse study was conducted using winter wheat as the test crop. The objectives of this study were as follows:

1. To evaluate the effect N and P fertilizer banded with the seed has on the uptake of P from the preplant band in both plants over and plants to the side of a preplant band.
2. To study P uptake from seed-banded fertilizer by plants growing either over or to the side of a preplant band.

LITERATURE REVIEW

Banded applications of fertilizer

Fertilizer application methods can be classified in two broad classes of application: broadcast and localized. Broadcast implies a uniform fertilizer application over the soil surface, whereas localized refers to fertilizer applications in concentrated zones. Fertilizer bands are a type of localized application which, under certain conditions, can be superior to broadcast applications in terms of crop growth and grain yield (Leikam, 1980; Dann, 1969).

The relative efficiency of banded over broadcast applications depends partially on the kind of nutrient applied (Bear, 1941). The importance of banded placement is not the same for the three major plant nutrients (N,P,K) because of their different chemical properties (Welch et al., 1966).

Nitrogen (N) is a mobile soil nutrient when in the nitrate form because it is not adsorbed appreciably by the soil and moves with soil water flow (Young and Aldag, 1982). Therefore, banded N applications may not be much different from broadcast applications since N can move from bands into non-fertilized soil.

Phosphorus (P) is an immobile soil nutrient because soil fixation reactions limit its movement (Sample et al., 1980). Since P fixation converts solution P to less soluble compounds, application of P fertilizer in restricted soil zones may show advantages over broadcasting. Band placement of water-soluble P fertilizer can exceed the soil's "fixation capacity" reducing the amount of P fixed. This should result in more soil solution P around the band, which in turn, may increase the P uptake by roots nearby. Such increases in P uptake are likely in soils low in solution P levels. Increased P uptake by roots in the band should increase plant P content if a sufficient portion of the root system contacts the applied fertilizer (Barber, 1980).

Water solubility of the P fertilizer used, initial soil P level, and type of root system are, therefore, important factors determining the relative efficiency of banded over broadcast applications of P fertilizer.

Fertilizer sources low in water soluble P should reduce band effectiveness because small amounts of P would be present in solution at any one time. Materials low in water soluble P perform better when broadcast on acid to neutral soils since reactions in such soils increase their water solubility (Engelstad and Terman, 1980).

The advantage of banded over broadcast P applications would be expected to decrease as the level of available P in the soil increases. Any increase in soil solution P from banding would not be as important in soils with high solution P levels as in soils with low solution P levels (Welch et al., 1966).

The relative efficiency of banded over broadcast P applications would also be different for crops with different root systems. Crops with restricted root systems are less efficient users of soil P and benefit more from a localized placement than crops with extensive root systems (Cooke, 1954).

Potassium (K) is also an immobile nutrient because attraction to soil cation exchange sites restricts its movement. In addition, some soils have a high capacity to fix K under non-exchangeable forms (Rich, 1968). Thus, banding K fertilizer may show advantages over broadcast applications for soils low in exchangeable K, particularly for crops of restricted root range (Tisdale and Nelson, 1975).

The advantages of banding over broadcasting fertilizer may be larger when two or more nutrients are applied simultaneously. Intimate placement of two or more nutrients can result in increased plant uptake of some of those nutrients due to interactions among them. Typical examples of these interactions are the increase in P uptake due to the presence of N (Miller et al., 1970), and the increase in N uptake due to the presence of P (Hills et al., 1970).

Effect of banded applications on root growth

Several workers have reported the application of N and P fertilizer in a band to have a stimulating effect on root growth in the band. Duncan and Ohlrogge (1959) found that when ammonium sulfate was added to superphosphate in a small volume of soil, corn root distribution was not uniform, but concentrated in the soil volume containing the N and P fertilizers. The authors emphasized that the increased root growth did not affect the shoot/root ratio, but instead changed the distribution of roots in the soil.

Duncan and Ohlrogge (1958) also investigated the nature of the root growth induced by localized placement of N and P fertilizer. They allowed single corn roots to develop in graduated cylinders containing bands of ammonium sulfate and superphosphate, placed either singly or in combination. A mass of fine roots developed when N and P were applied together. Much less root development occurred in bands of P alone, and almost no development in bands of N alone. The authors reported uptake of P to be correlated with root development in the N-P band. They also pointed out that the root weight increase obtained in the N-P band was not the only factor that increased the feeding capacity of the plant in the fertilizer band. Since roots in the band were much finer than roots in non-fertilized soil, the resulting increase in root surface area was much greater than the increase in root weights would indicate.

Grunes et al. (1958) reported that banding ammonium sulfate or sodium nitrate together with superphosphate considerably increased the proportion of barley roots in the fertilizer band, when compared to banding superphosphate alone. The addition of N increased the proportion of roots in the band by 162 to 342% depending on the soil.

Miller and Ohlrogge (1958) similarly observed that N as ammonium sulfate added to a band of superphosphate increased the weight of corn roots in the band. The ratio of observed root weight in the band divided by the expected weight if equal distribution occurred was 1.5.

Stimulation of root growth in a fertilizer band seems universal unless conditions in the band exceed growth limitations. Allred and Ohlrogge (1964), when studying the effect of ammonium phosphates on germination and emergence of corn, observed that early root development near monoammonium phosphate (MAP) bands was more extensive than near diammonium phosphate (DAP) bands. At the end of the experiments (10 days), roots were found within the salt zones surrounding the MAP bands, but no roots were observed within the DAP bands. Free ammonia in the DAP band was the attributed reason.

Passioura and Wetselaar (1972) studied growth of wheat roots in bands of urea and ammonium sulfate and after 2 weeks found no roots within a 10 cm (diameter) zone around the fertilizer bands. This was attributed to unfavorable osmotic potential in the fertilizer affected zone. Roots proliferated into the band of ammonium sulfate but were not into the band of urea at either 4 or 8 weeks. The authors suggested that the absence of roots in the urea band could have been due to the large amounts of nitrate present in the band.

In summary, the growth of wheat roots may be stimulated in bands of N and P fertilizer if toxic substances or osmotic stress are minimized. Such stimulations may result in less root development in other regions of the root zone where nutrient and water uptake, depending largely on extensive root-soil contact, may be adversely affected.

Types of banded applications

The most used types of banded applications are the following (Tisdale and Nelson, 1975):

a) Preplant-banded, in which the fertilizer is applied preplant in bands 10-20 cm deep and 25-50 cm apart.

b) Seed-banded, in which the fertilizer is placed with the seed at sowing.

c) Side-banded, in which the fertilizer is placed in bands to one or both sides of the seed at sowing.

d) Side-dressed, in which the fertilizer is banded to the side of the crop after emergence.

Of these, preplant-banded and seed-banded applications will be considered in detail since they are typically used in wheat production and they represent the types of applications used in the present study.

Preplant banded applications. These applications present an important practical advantage over broadcast applications; namely, the possibility of combining preplant banding with a tillage operation to eliminate one trip over the field.

Preplant-banded applications can present a particular agronomic advantage in dry years since nutrient placement in deep bands provide better positional availability. When dry-land wheat receives abundant rainfall, distributed in several showers during the growing season, depth of nutrient placement (up to 20 cm) does not affect grain yield or nutrient uptake (Prihar et al., 1977). But, when limited rainfall is received after sowing, grain yield and nutrient uptake increase as the depth of N and P increases (up to 20 cm).

Similar results by Singh et al. (1976) showed that under rainfed conditions, placement of N 10-15 cm below the seed is important for increasing fertilizer and water use efficiencies by wheat. Deep placement of N fertilizers can also reduce N immobilization by decomposing residues in areas where surface stubble mulch is used (Andrews, 1956).

Field experiments on soils testing low in available P (Leikam, 1980) have shown preplant-banded applications of N and P fertilizer to increase winter wheat grain yields in Kansas, when compared to broadcast applications. These applications were useful for increasing early crop growth at most sites, including those where final grain yield increases were not obtained. Leikam observed that a 46 cm band spacing resulted in rows above a preplant band showing more vegetative growth than those between preplant bands. This "wavy effect" was more noticeable early in the spring but was difficult to see at harvest time.

Maxwell (1980), using field studies in eastern Kansas, evaluated the effects of preplant band spacing (25,38, and 50 cm) and P fertilizer rate on winter wheat. He found the spacings used had no significant effects on grain yields although yields tended to be higher with narrower spacings at some locations. Spacings of 25 and 38 cm gave more uniform plant growth and dry matter production early in the growing season. Detailed plant samplings conducted at different distances from the preplant band showed an increase in spike number on plants directly over the bands spaced 50 cm apart as compared to the 25 and 38 cm spacings. The author suggested this increase in spike number could compensate for the lower spike number found on plants between bands at the 50 cm spacing. He added that this compensatory effect might explain why the 25 and 38 cm spacings, in spite of giving more uniform plant growth and spike number, did not result in higher grain yields than the 50 cm spacing.

MacMillan et al. (1971) conducted field studies to select an appropriate row spacing for urea applied to wheat grown for winter fodder in New Zealand. The fertilizer was applied in bands at a depth of 7.5-10 cm and at spacings varying from 15 to 75 cm in increments of 15 cm. Increasing band spacing decreased dry matter yield of wheat by about 5% for every 15 cm increment. Response to the urea was observed in plants within 20 cm of the application.

Maxwell (1980) conducted a greenhouse study to evaluate the effect of distance from the preplant band on P absorption by winter wheat. He found that wheat seedlings placed directly over or 10 cm to the side of a N-P preplant band absorbed more P than seedlings placed 20 or 30 cm to the side of a preplant band. He concluded that close proximity to the preplant band is important for maximum P uptake and dry matter production in the early growth.

To summarize, preplant-banded applications of N and P fertilizer in winter wheat are likely to increase grain yields, when compared to broadcast applications, in soils testing low in available P. These applications should show a particular advantage whenever the topsoil remains relatively dry during the early part of the growing season. The increases in early vegetative growth obtained with this method can be of some value to livestock producers who use wheat for grazing purposes.

Seed-banded applications. Placing the fertilizer with the seed (seed-banded) allows crop seedlings early access to the applied nutrients. In this sense, seed-banded fertilizer can be of significant value to rapidly growing crops with a restricted root range like cereals (Cooke, 1954). However, an important disadvantage of this method is that nutrient absorption from the band can be limited if the topsoil becomes dry soon after emergence (Boatwright et al., 1964). Seed-banded applications also present the practical disadvantage of requiring extra time and labor at seeding time when both may be in limited supply.

The effect of banding fertilizer with the seed on crop growth depends on the amounts and kinds of nutrients applied. Excessive levels may reduce or delay germination, affecting seedling establishment.

There are at least two ways in which fertilizers in contact with the seed can affect seedling establishment (Carter, 1967). First is a direct toxic effect some chemical substances have on germinating seeds. Examples of this are biuret in urea (Smika and Smith, 1957; Brage et al., 1960), and fluoride in superphosphate (Kinra et al., 1962). Ammonia vapor released by some N fertilizers can also be very toxic to germinating seeds (Allred and Ohlrogge, 1964; Brage et al., 1960). Secondly, fertilizers can affect seedling establishment through an osmotic effect. Germination is strongly affected by salt concentrations, especially at low soil moisture levels (Chapin and Smith, 1960).

Nutrient levels that can be safely applied with the seed depend on the nutrients under consideration. Nitrogen and K fertilizers are more detrimental to germination than fertilizers containing only P (Cummins and Parks, 1961; Lawton and Davis, 1960). Therefore, larger application rates can be used with P fertilizers than with N or K fertilizers.

Extensive research has been conducted to study the suitability of seed-banded applications for wheat. Olson and Dreier (1956), in field and greenhouse studies in Nebraska, evaluated the effects of time and method of fertilizer application on small grains. They found the efficiency of fertilizer P to be greater when applied with the seed than when broadcast at different times. Also, the application of P fertilizers (no N or K) with the seed did not significantly reduce emergence even under low soil moisture levels. On the other hand, serious stand reductions occurred under low soil moisture levels when 12 or more kg of N per hectare were placed in contact with the seed. The authors concluded that no more than 18 kg N/ha should be applied with the seed to avoid germination damage.

In field studies with winter wheat in Kansas, Duley (1930) compared applications of 210 kg/ha of 2-5.2-1.6 and superphosphate under four methods: broadcast, banded with the seed, banded 2 cm above the seed, and banded 2 cm below the seed. These experiments were conducted in low fertility soils. Banding fertilizer with the seed was better than broadcast and slightly better than banding above or below the seed in terms of straw production and grain yield. Plants fertilized in the row were taller and produced more tillers than those that received broadcast fertilizer. Therefore, he concluded the increase in grain yield obtained when the fertilizer was banded with the seed was mostly from an increased number of spikes.

In field studies in Australia, Dann (1969) found that at two of four sites, applications of superphosphate with the seed of wheat were superior to broadcast applications in terms of dry matter production, productive tillers, grain yield, and mean kernel weight.

Recently, Peterson et al. (1981) carried out field experiments in Nebraska to determine if a consistent relationship exists between broadcast and row applied P for winter wheat yields. The relative effectiveness of row and broadcast applications varied depending on soil test P level. In soils with low levels of available P, broadcast P rates had to be three times as high as row P rates in order to obtain the same grain yield response. In soils with medium levels of available P, broadcast P rates equal to row P rates produced similar grain yield responses.

Alessi and Power (1980) determined the effects of banded and residual fertilizer P on spring wheat yield in North Dakota. They broadcast rates of 0, 20, 40, 80, and 160 kg P/ha in 1968 to establish different levels of residual P in a Parshall fine sandy loam. Then, in 1969, subplots were established on each of the broadcast P plots. Some of the subplots did not receive any more fertilizer, while others received P banded with the seed at the rate of 15 kg/ha either repeated on the same subplot each year, for 6 years, or on a new subplot previously unfertilized, each year. After 6 years of cropping, the residual effects of 160 kg/ha broadcast in 1968 increased grain yields by about 10%. Applying P with the seed increased grain yields an additional 10%, with about half of that increase due to current year banding and about half due to residual effects of banding in previous years. Banding P with the seed also produced significant increases in dry matter yield. The favorable effects of banding P with the seed were even observed in soils with high levels of available P, according to a soil test. Therefore, the authors concluded that applying P with the seed may be desirable for spring wheat in the Northern Great Plains, regardless of the level of available P in the soil.

Knapp and Knapp (1978) studied the response of winter wheat to date of planting and fall fertilization in central New York. The soils used for the experiment were of medium P level. Nitrogen and P were banded at planting time at the rates of 0 N and 0 P, 0 N and 20 kg P/ha, 22 kg N/ha and 0 P, and 22 kg N/ha and 20 kg P/ha. The authors observed that P alone or with N increased winter survival and grain yield. Increases in grain yield were attributed to increases in the number of spikes per unit area and mean kernel weight. Nitrogen applied alone had little effect on grain yield and grain yield components. The authors concluded that in their area, the application of P with the seed is important to improve tillering and winter survival, especially at late planting dates.

To summarize, seed-banded applications of N and P fertilizer in winter wheat can be useful to increase early growth. This vegetative growth increase could result in increased grain yields in soils testing low in available P or in areas with low temperatures during the early stages of growth. In such cases, the grain yield increases would probably result from increases in the number of spikes per unit area, although increases in mean kernel weight could also be obtained.

MATERIALS AND METHODS

Field Studies.

Field studies were conducted at three locations in two Kansas counties over the 1980-81 and 1981-82 crop years (Figure 1). Soil type and soil analytical data for these locations are presented in Tables 1 and 2. Dates for fertilizer application, seeding, and grain harvest, as well as seeding rates and cultivar used are given in Table 3.

1980-81 Study.

The 1980-81 study was conducted in Dickinson county. Recent crops and fertilizer applications at this site are presented in Table 4.

The experimental design used was a split plot where three rates of preplant-banded fertilizer (112-0, 112-10, and 112-20 kg/ha of N and P, respectively) were the main plot treatments and five rates of seed-banded fertilizer (0-0, 1.5-2.5, 3-5, 6-10, and 12-20 kg/ha of N and P, respectively) the subplot treatments. The main plot treatments were arranged in a randomized complete block design with four replications, whereas the subplot treatments were completely randomized within each main plot. The subplots were 3.05 x 9.15 m.

The preplant treatments were formulated with liquid ammonium polyphosphate (10-14.8-0) and urea-ammonium nitrate solution (28-0-0) and were applied 16 days before sowing. These applications were made with an applicator equipped with shanks which placed

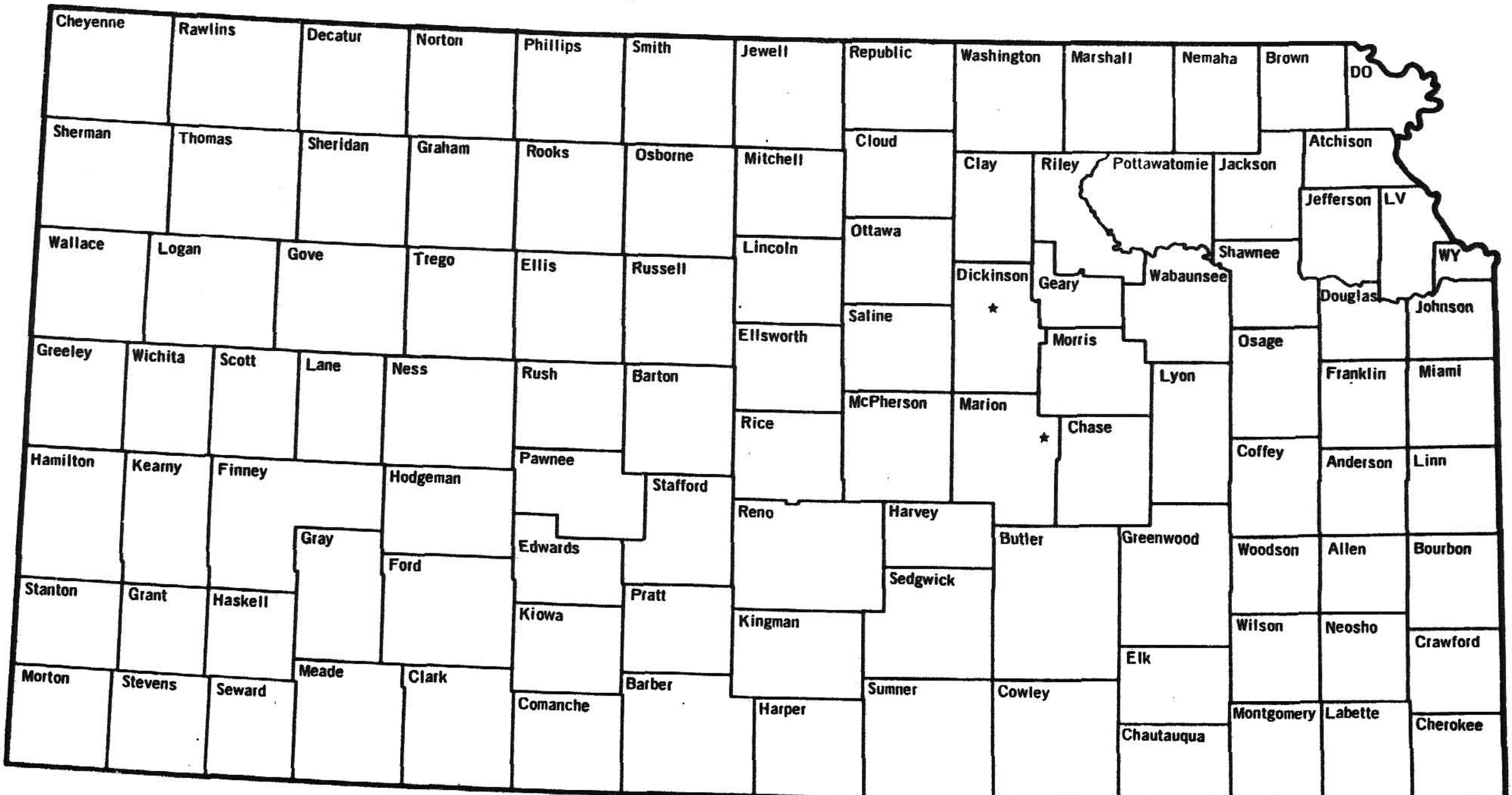


Fig. 1. Location of the 1980-81 and 1981-82 field studies. (The two sites in Dickinson Co. are denoted by a single star in the map).

Table 1. Soil texture and classification.

County	Location	Texture	Series	Family and higher taxonomic class
Dickinson	J. Hoover Farm (1980-81)	Silty clay loam	Crete	Fine, montmorillonitic, mesic Pachic Argiustoll
Dickinson	J. Hoover Farm (1981-82)	Silty clay loam	Crete	Fine, montmorillonitic, mesic Pachic Argiustoll
Marion	E. Broz Farm (1981-82)	Silty clay loam	Reading	Fine, mixed, mesic Typic Argiudoll

Table 2. Soil test levels and general site information.

County	Location	Date sampled	Soil depth (cm)	% O.M.	pH	NO_3-N	NH_4-N	P	K
						---------mg/kg-----------			
Dickinson	J. Hoover Farm	9/19/80	0-15	3.2	5.9	---	---	8	248
	(1980-81)		15-30	3.3	5.8	---	---	7	248
Dickinson	J. Hoover Farm	8/19/81	0-15	2.5	6.2	5.7	8.9	11	273
	(1981-82)		15-30	1.6	6.9	4.5	6.9	4	293
			30-60	1.3	7.6	6.7	6.5	3	283
			60-90	0.6	8.1	5.6	6.4	8	266
Marion	E. Broz Farm	9/17/81	0-15	2.6	6.1	28.3	9.0	13	265
	(1981-82)		15-30	2.9	6.1	23.1	7.7	9	241
			30-60	2.8	6.2	19.7	8.1	7	276
			60-90	2.9	6.2	15.3	7.5	8	327

Table 3. Dates of fertilizer applications, seeding, tissue samplings, tiller counts, and grain harvest, seeding rate and cultivar used in each location.

County	Location	Dates				Seeding		Cultivar
		Preplant-banded applications	Tissue samplings	Tiller counts	Grain harvest	Date	Rate (kg/ha)	
Dickinson	J. Hoover Farm (1980-81)	9/19/80	3/14/81 5/2/81	12/5/80 2/28/81	6/29/81	10/6/80	160	Newton
Dickinson	J. Hoover Farm (1981-82)	9/18/81	3/27/82	3/27/82	7/5/82	10/7/81	90	Newton
Marion	E. Broz Farm (1981-82)	9/29/81	4/3/82	4/3/82	7/2/82	10/8/81	90	Newton

Table 4. Previous crops and fertilizer applications in each site.

County	Location	Year	Crop	Fertilizer Applied N	Fertilizer Applied P	Lime applied
				------kg/ha-------		---kg/ha----
Dickinson	J. Hoover Farm	1979	Wheat	20	22	-----
	(1980-81)	1980	Oats	67	0	-----
Dickinson	J. Hoover Farm	1980	Sorghum	80	0	-----
	(1981-82)	1981	Oats	50	0	-----
Marion	E. Broz Farm	1967-80	Alfalfa	0	0	-----
	(1981-82)	1981	Wheat	72	22	6,720

the fertilizer solution in bands 15-20 cm deep and 46 cm apart. In order to determine the location of the preplant bands after planting, flags were placed over the bands at the time of the application. The seed-banded treatments were formulated with liquid ammonium polyphosphate (10-14.8-0) and were applied through a delivery tube (in the drill) which placed the fertilizer solution in contact with the seed.

The wheat was drilled in rows perpendicular to the preplant band using an Ontario drill with nine disk openers spaced 17.8 cm apart.

Detailed tiller counts and spike samplings were conducted in the main plots with the highest rate of preplant-banded fertilizer (112 and 20 kg/ha of N and P, respectively). For that purpose, two 60 cm row sections in each subplot were thinned to a density of 5 plants per 11.5 cm of row (246 plants/m^2), and then flags were placed to separate three areas along each row. The 11.5 cm of row centered over a preplant band constituted an "A" area, the next 11.5 cm to the side formed a "B" area, and the next 11.5 cm of row, centered between two preplant bands, constituted a "C" area (Figure 2). These areas were used for in-situ tiller counts at the early tillering stage (5 December), and at the advanced tillering stage (28 February). The results were expressed as number of tillers/m^2 in each area. The marked areas were also used for spike samplings at harvest to determine number of spikes/m^2, number of kernels/spike, mean kernel weight, grain yield/m^2, and grain protein and P concentrations in each area.

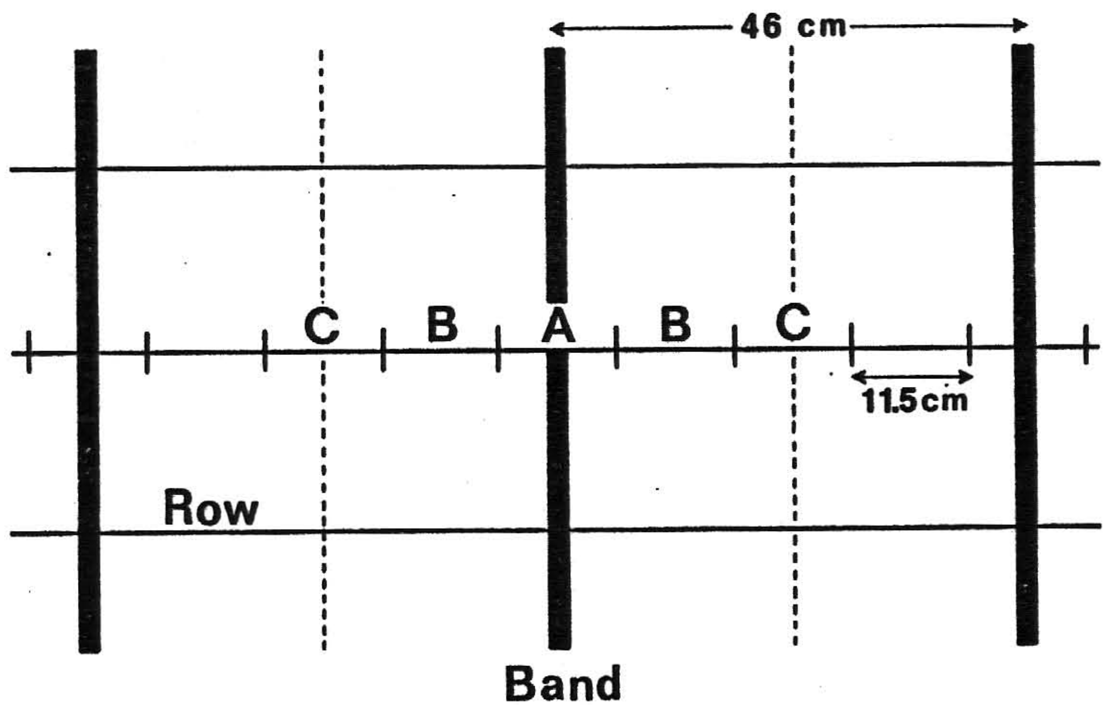


Fig. 2. Diagram showing location of the row areas used for tiller counts, plant samplings, and spike samplings.

All the results involving grain weights were expressed on a moisture basis of 0.125 kg/kg. Tiller survival in each area, for each treatment, was calculated as follows:

$$\% \text{ tiller survival} = \frac{\text{tillers/m}^2 \text{ at the advanced tiller stage}}{\text{spikes/m}^2 \text{ at harvest}} \times 100$$

Tissue samples from areas A, B, and C were taken from all the subplots at the advanced tillering stage (14 March) and at anthesis (2 May). At each sampling date, the plants in three areas A, B, and C, in each subplot, were clipped at the soil surface, placed in paper bags, and taken to the laboratory. These samples were used to determine dry matter/m^2 and tissue N and P concentrations in each area.

1981-82 Studies.

The 1981-82 studies were carried out in Dickinson and Marion counties. Recent crops and fertilizer applications at these sites are presented in Table 4. The experimental design used was the same as that used in 1980-81, but fertilizer rates, subplot dimensions, and sampling methods were different.

The rates of preplant-banded fertilizer were 70-0, 70-9, and 70-18 kg/ha of N and P, respectively, whereas the rates of seed banded fertilizer were 0-0, 15-0, 15-4.5, 15-9, and 15-18 kg/ha of N and P, respectively. The preplant-banded applications were made 16 and 7 days before sowing at Dickinson and Marion counties, respectively.

The subplots were 2.40 x 11.60 m, and were planted using an International drill with twelve disk openers spaced 20 cm apart. An area 2.40 x 2.45 m, at the end of each subplot, was used for sampling areas A, B, and C along the crop row, and was not included in the final harvest.

Plant samplings were conducted at the advanced tillering stage (27 March and 3 April in Dickinson and Marion counties, respectively) and at harvest. At the advanced tillering stage, the plants in three areas A, B, and C, in each subplot, were dug and placed in plastic bags. These samples were taken to the laboratory where tillers were counted and dry matter weights and tissue N and P concentrations were determined. The results were expressed as number of tillers/m^2, dry matter/m^2, and percentages of N and P in the tissue. At harvest time, the spikes in three areas A, B, and C, in each subplot, were collected, placed in paper bags, and taken to the laboratory. These samples were processed to determine number of spikes/m^2, number of kernels/spike, mean kernel weight, grain yield/m^2, and grain protein and P concentrations in each area. All the results involving grain weights were expressed on a moisture basis of 0.125 kg/kg. Tiller survival was calculated as described previously.

At all locations, grain yields were estimated by harvesting an area 1.95 x 9.15 m in the center of each subplot. A model E Allis Chalmers combine, specifically rebuilt for small plot harvesting, was used for that purpose. A sample of grain from each subplot was saved for moisture determination and chemical analysis. Grain yields and grain protein and P concentrations were then adjusted to a moisture content of 0.125 kg/ha.

Temperature and precipitation data for both years, at Herington, are presented in Appendix Figures A-1, A-2, and A-3. These data were collected by an official observer of the National Weather Service. The sites in Dickinson county are approximately 40 km north of Herington, whereas the site in Marion county is approximately 30 km south of Herington.

Greenhouse Study.

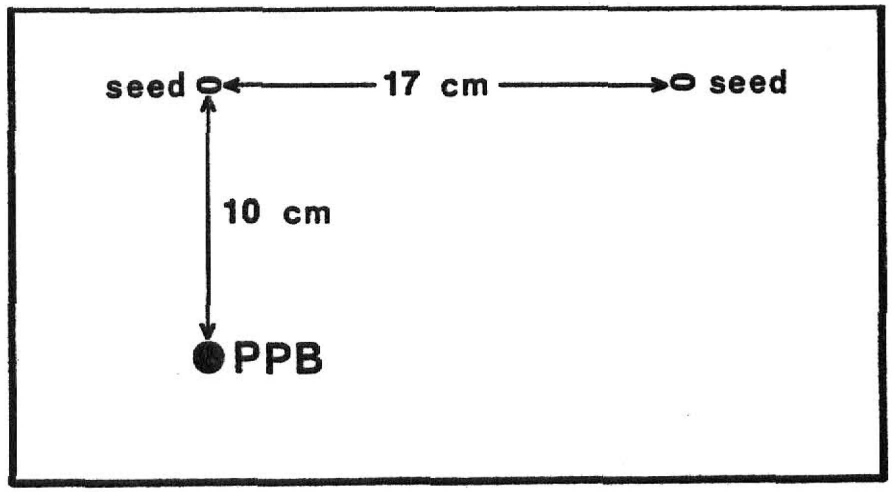
In the fall of 1981, a greenhouse experiment was conducted to study the absorption of P from seed-banded and preplant-banded fertilizers by wheat plants growing either over or to the side of a preplant band.

The soil used was collected from the upper 20 cm of soil at the site of the 1981-82 field study in Dickinson county. The soil was collected on 19 August and kept in covered plastic containers until the end of October. Then it was sieved through a 5 mm screen, mixed, and subjected to chemical analyses. Soil chemical analyses (as of 26 October) and particle size distribution are presented in Table 5.

The treatments were arranged in a split plot design where the main plots were eight plastic boxes (32 x 27.5 x 17 cm deep) which contained two rows (17 cm apart) of Newton wheat each, and one preplant band placed 10 cm directly below one of the wheat rows (Figure 3). The rate of fertilizer in the preplant band was equivalent to 70 kg N/ha and 13 kg P/ha. The subplots were the wheat rows within a box.

Table 5. Particle size distribution and soil test levels in soil used for the greenhouse study.

Sand	Silt	Clay	%		NO_3-N	NH_4-N	P	K
	%		O.M.	pH		mg/kg		
16.4	49.0	34.6	2.5	6.0	16.1	7.7	16	435



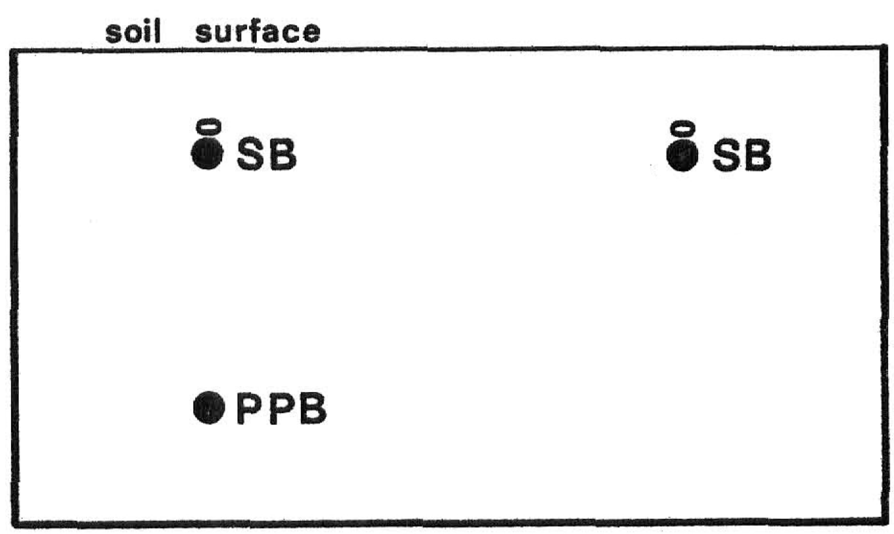


Fig. 3. The upper diagram shows a cross-sectional view of a box without seed-banded fertilizer. The lower diagram shows a cross-sectional view of a box with seed-banded fertilizer. (SB = seed-banded fertilizer; PPB = pre-plant-banded fertilizer).

The main plot treatments were two rates of seed-banded fertilizer (0-0, and 15-4.5 kg/ha of N and P, respectively), whereas the subplot treatments were two locations of the wheat row with respect to the preplant band (over or to the side of the preplant band). The main plot treatments were arranged in two replications of a 2 x 2 latin square design so that there would be four rows and two columns. The subplot treatments were completeley randomized within each main plot.

The sources of N and P used in the prepland bands and seed bands were reagent grade ammonium nitrate and diammonium phosphate. The P applied in the preplant band was labeled with ^{32}P, whereas the P applied in the seed band was labeled with ^{33}P.

The N solution for the preplant band was prepared by dissolving 14.6 g of ammonium nitrate in 25 mL of deionized distilled water; 2.5 mL of this solution was then used in each box. The N solution used in the seed band was prepared by dissolving 1.39 g of ammonium nitrate in 25 mL of deionized distilled water; 5 ml of this solution (2.5 mL per wheat row) was used in each of the four boxes that received seed-banded fertilizer. The balances of N needed to apply the desired N rates were added with the P solution (diammonium phosphate).

To prepare the P solution for the preplant band, 4.9 g of diammonium phosphate was dissolved in 10 mL of deionized distilled water, and then 3.7×10^8 Bq (10 mCr) of ^{32}P was added. This solution, diluted with distilled water to a final volume of 25 mL, constituted the ^{32}P stock solution, 2.5 mL of this solution was used in each box. The P solution for the seed band was prepared by dissolving 0.82 g of diammonium phosphate in 10 mL of deionized distilled water, adding 3.7×10^7 Bq (1 mCr) of ^{33}P, and diluting with distilled water to a final volume of 25 mL. This solution constituted the ^{33}P stock solution; 5 mL of this solution (2.5 mL per wheat row) was used in each of the four boxes that received seed-banded fertilizer.

The following procedure was used to fill the boxes. First, 3,924 g of soil (with average gravimetric water content (w) of 0.173 kg/kg) was added and compacted into a layer 4 cm thick. Distilled water was then added to raise the moisture content to w = 0.30 kg/kg. The boxes were covered with plastic and the soil was allowed to equilibrate overnight. Next morning, the preplant band was applied by delivering the corresponding volumes of the N and P solutions in a narrow band, by means of a pipette. Then, four consecutive amounts of soil weighing 2,452 g each (w = 0.173 kg/kg) were added and compacted to a thickness of 2.5 cm each. These additions increased the total depth of soil to 14 cm. Next, 1,060 g of distilled water was added to raise the water content of the added soil to w = 0.30 kg/kg. The soil was again allowed to equilibrate overnight, and next morning the seed-banded fertilizer was applied. This application was made by delivering the corresponding volumes of the N and P solutions in narrow bands, by means of a pipette. The fertilizer bands were covered with a loose layer of soil 0.6 cm thick and then 28 Newton wheat seeds were placed right above each band. The thin layer of soil between the fertilizer and the seeds was intended to reduce the possibilities of seed injury due to the radiation emitted by ^{33}P. The seeds were covered with 2,943 g of soil (w - 0.173 kg/kg) which was packed in a layer 3 cm thick. Finally, 318 g of distilled water was added to raise the water content in the last layer of soil to w = 0.30 kg/kg. The estimated dry bulk density obtained was approximately 0.95 Mg/m^3.

In order to reduce water losses by evaporation, the boxes were kept covered with paper until emergence. Just before emergence, enough distilled water was added to raise the water content to w = 0.30 kg/kg with the purpose of eliminating the surface crust and facilitate emergence. From then on, the boxes were weighed periodically, and water was added when the weights indicated that in most of the boxes the water content had decreased to approximately 0.20 kg/kg. Each time water was added,w was raised to approximately 0.30 kg/kg.

The wheat, planted on 6 November, was grown for 40 days in the greenhouse, with total above-ground plant parts sampled every 10 days. Twelve plants per row were taken in the first sampling, four in the second, and three in the following samplings. These samples were used to determine the number of tillers/plant, average plant weight, tissue N and P contents, and amounts of P absorbed from the seed-banded and preplant-banded fertilizer, respectively.

The temperature control in the greenhouse was adjusted to obtain temperatures similar to those normally occurring in the field during the month of October. Ten-day averages of air relative humidity and soil temperature at 8 cm of depth, at 8 a.m. and 2 p.m. are given in Appendix Table A-1.

Laboratory analyses.

Field studies.

Tissue samples. Tissue samples from the field studies were dried in a forced air oven (at 60°C for 5 days), ground through a Udy rotary-abrasion mill, and stored in sealed, plastic vials. Prior to weighing of samples for chemical analyses, the vials were placed in an oven at 45°C for 24 h.

A 0.25 g of ground tissue was placed into a digestion tube and 2 mL of concentrated H_2SO_4 acid was added. The tubes were then placed under a hood in an aluminum digestion block, and 1 mL of 30% H_2O_2 was added to each tube. The samples were heated at 300°C with subsequent additions of 1 mL of 30% H_2O_2 until the digest solution remained clear (Linder and Harley, 1942). The digests were then removed from the digestion block, diluted to 50 mL with distilled water, and stored in polyethylene bottles. The determinations of total N and P were carried out on these diluted solutions using a Technicon Auto Analyzer. The N determinations were made with a colorimetric method in which an emerald-green color is formed by the reaction of ammonia, sodium salicylate, sodium nitroprusside, and sodium hypochlorite in a medium buffered at a pH of 12.8 to 13.0. The ammonia - salicylate complex was read at 660 nm. The P determinations were made using a colorimetric method in which a blue color is formed by the reaction of orthophosphate, molybdate ion, and antimony ion, followed by reduction with ascorbic acid at an acidic pH. The resultant complex was read at 660 nm (Technicon Industrial Systems, 1977a).

Grain Samples. Grain samples were ground through a Udy-rotary abrasion mill and stored in sealed, plastic vials. Ground grain samples were then handled and analyzed for N and P contents in the same way as described for tissue samples. The percent protein in the grain was calculated by multiplying the percent N in the grain by a factor of 5.7.

Soil samples. Soil samples were analyzed by the Soil Testing Laboratory at Kansas State University.

The organic matter content was determined by subjecting the soil sample to wet oxidation by potassium dichromate and sulfuric acid, and then reading the green color of the oxidized reagent at 620 nm (Carolan, 1948).

To determine pH, 5 g of soil were mixed with 5 mL of deionized water and then the mixture was allowed to stand for 10 minutes. The sample was then stirred and the pH measured.

The NH_4-N and NO_3-N levels were determined on a KCl extract (2 g of soil and 20 mL of 2N KCl) using a Technicon Auto Analyzer. The NH_4-N determinations were made with the same method used to determine N content in tissue samples. The NO_3-N determinations were made using a procedure whereby nitrate is reduced to nitrite in a copper-cadmium reductor column. The nitrate ion then reacts with sulfanilamide (under acidic conditions) to form a diazo compound, which in turn couples with N-1-naphthylethylene diamine dihydrochloride to form a redish-purple azo dye. This color was then read at 520 nm (Technicon Industrial Systems, 1977b).

Bray-1 phosphorus (Bray and Kurtz, 1945) was determined on 5 mL of an extract prepared by shaking 1 g of soil with 10 mL of extractant (0.025 N HCl in 0.03 N NH_4F) for 40 seconds. The blue color developed (after the addition of 0.25 mL of acid molybdate solution and 0.25 mL of dilute reducing agent) was read at 650 nm.

Exchangeable K was determined on an extract prepared by shaking 5 g of soil with 25 mL of extractant (1 N NH_4OAc pH 7.0) for 10 minutes (Mervin and Peech, 1950). Potassium in solution was measured using a flame spectrophotometer.

Greenhouse study.

Tissue samples. Tissue samples from the greenhouse study were placed in paper bags and dried in an oven at 55°C for at least 6 days. The samples were then cut into small pieces (<0.5 cm) with scissors, since the small amounts of sample available did not allow the use of a grinder.

A known weight of tissue (approximately 0.12 g) was placed into a digestion tube and digested as described previously for tissue samples from the field studies; the final digests were diluted to 25 mL instead of 50 mL. The N and P content determinations were carried out on these diluted solutions using a Technicon Auto Analyzer, as described previously. Aliquots of these digests were also used for assays of radioactivity to determine the amounts of P absorbed from the ^{32}P-labeled preplant-banded fertilizer, and from the ^{33}P-labeled seed-banded fertilizer. The samples from each sampling date were assayed for radioactivity immediately after the sulfuric digestion was completed.

Assay of radioactivity. The ^{32}P and ^{33}P isotopes are both beta emitters. The ^{32}P isotope has an E_{max} of 1.71 million electron volts (MeV) and a half-life of 14.3 days, whereas the ^{33}P isotope has an E_{max} of 0.250 MeV and a half-life of 25.4 days. The beta particles emitted by these isotopes have different energy distributions, which allows the determination of the amount of radiation coming from each isotope,when both isotopes are present in a sample. In this study, a dual-channel liquid scintillation counter (Beckman LS-200B) was used for that purpose. Channel A recorded all of the ^{33}P counts and a fraction of the ^{32}P counts, while channel B recorded the other fraction of the ^{32}P counts and no counts from ^{33}P (Figure 4).

Counts were taken in three types of samples: counting standards for each of the isotopes, sample digests with ^{32}P and ^{33}P, and sample digests with only ^{32}P. The counting standard for ^{32}P was used to determine the fraction of the total ^{32}P counts recorded by each channel. This counting standard was also used to determine the actual amounts of P coming from the ^{32}P-labeled fertilizer in each of the samples that contained ^{32}P. The counting standard for ^{33}P was used to determine the actual amounts of P coming from the ^{33}P-labeled fertilizer in each of the samples that contained ^{33}P.

Each of the samples was counted for at least 5 min and the readings were expressed as counts per minute (CPM). The reading obtained in each channel was corrected for background radiation by substracting from it the average reading of samples containing sulfuric digests of control plants (plants that contained no labeled P).

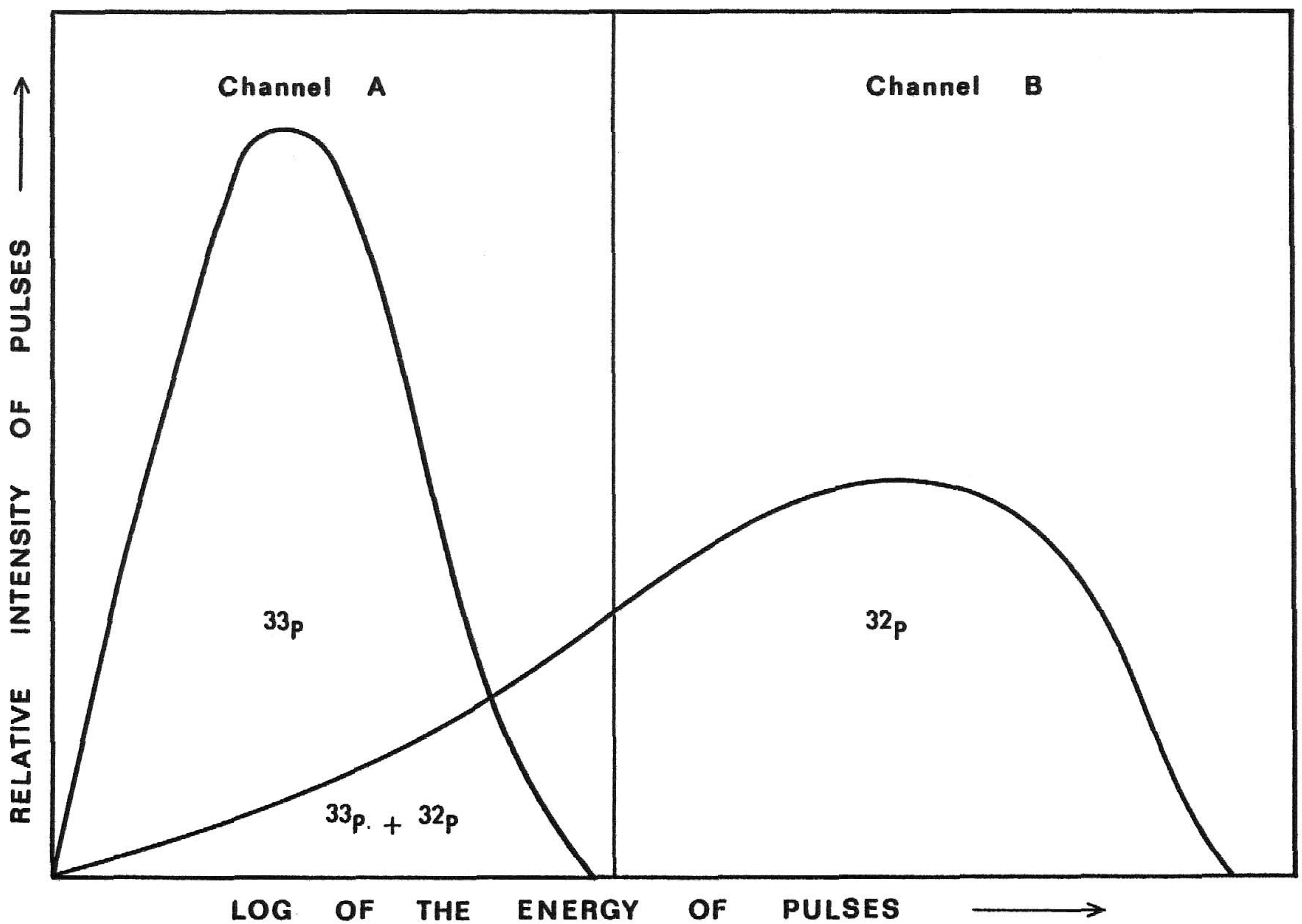


Fig. 4. Energy distributions of ^{32}P and ^{33}P, and fractions recorded in each channel.

The first step in the preparation of the counting standards for ^{32}P and ^{33}P was to prepare standard solutions from the stock solutions used in the preplant bands and seed bands, respectively. The ^{32}P standard solution was made by pipetting 5 µL of the ^{32}P stock solution into a 25 mL volumetric flask and then diluting to the mark with sulfuric digest of control plants. The ^{33}P standard solution was prepared by pipetting 10 µL of the ^{33}P stock solution into a 25 mL volumetric flask and diluting to the mark with sulfuric digest of control plants.

To make the ^{32}P counting standard, 2 mL of the ^{32}P standard solution was pipetted into a liquid scintillation vial to which, 2 mL of sulfuric digest of control plants and 15 mL of Aquasol (liquid scintillation cocktail obtained from New England Nuclear, in Massachusetts) had been added. The ^{33}P counting standard was prepared by pipetting 2 mL of the ^{33}P standard solution, 2 mL of sulfuric digest of control plants, and 15 mL of Aquasol into a liquid scintillation vial. Each sample digest was prepared for counting by pipetting 4 mL of digest and 15 mL of Aquasol into a liquid scintillation vial.

The CPM obtained in each channel for the ^{32}P counting standard was used in equations developed to determine the total CPM for ^{32}P and ^{33}P in sample digests containing both isotopes. The equations used for that purpose are as follows (Leikam, 1980):

Corrected CPM = Observed CPM - Background CPM

r_{32} = total corrected CPM for ^{32}P

r_{33} = total corrected CPM for ^{33}P

r_A = corrected CPM in Channel A

r_B = corrected CPM in Channel B

$R_{A,32}$ = corrected CPM for ^{32}P counting standard in Channel A

$R_{B,32}$ = corrected CPM for ^{33}P counting standard in Channel B.

$$r_A = r_{33} + r_{32} \left[\frac{R_{A,32}}{R_{A,32} + R_{B,32}}\right] \qquad (1)$$

Thus,

$$r_{33} = r_A - r_{32} \left[\frac{R_{A,32}}{R_{A,32} + R_{B,32}}\right] \qquad (2)$$

$$r_B = r_{32} \left[\frac{R_{B,32}}{R_{A,32} + R_{B,32}}\right] \qquad (3)$$

Thus,

$$r_{32} = r_B \left[\frac{R_{A,32} + R_{B,32}}{R_{B,32}}\right] \qquad (4)$$

substituting r_{32} in equation (2) for equation (4) gives:

$$r_{33} = r_A - r_B \left[\frac{R_{A,32} + R_{B,32}}{R_{B,32}}\right] \left[\frac{R_{A,32}}{R_{A,32} + R_{B,32}}\right] \qquad (5)$$

$$r_{33} = r_A - r_B \left[\frac{R_{A,32}}{R_{B,32}}\right] \qquad (6)$$

Therefore, equations (4) and (6) can be used to calculate the total CPM for ^{32}P and ^{33}P, respectively, in sample digests containing both isotopes.

Since only half of the boxes contained ^{32}P and ^{33}P, at the most only half of the samples contained both isotopes. The other samples contained only ^{32}P. The total CPM for ^{32}P in the sample digests containing only ^{32}P was calculated by adding the corrected CPM obtained in each channel:

$$r_{32} = r_A + r_B$$

The total CPM for the ^{32}P counting standard was also calculated by adding the corrected CPM in each channel. The total CPM for the ^{33}P counting standard was the corrected CPM obtained in channel A since channel B did not record any radiation from ^{33}P.

The total CPM for the ^{32}P counting standard and ^{33}P counting standard were used to determine the specific activities of the P applied in the preplant bands and seed bands, respectively:

$$\text{Specific activity of P in preplant band} = \frac{\text{Total CPM for } ^{32}\text{P counting standard}}{\text{mg P in } ^{32}\text{P counting standard}}$$

$$\text{Specific activity of P in seed band} = \frac{\text{Total CPM for } ^{33}\text{P counting standard}}{\text{mg P in } ^{33}\text{P counting standard}}$$

These specific activities were used to calculate the amounts of P coming from the preplant band and seed band, respectively, in each sample:

$$\text{mg P from preplant band in sample} = \frac{\text{Total CPM for } ^{32}\text{P in sample x 25 mL digest}}{\text{Specific activity of P in preplant band x 4 mL digest}}$$

$$\text{mg P from seed band in sample} = \frac{\text{Total CPM for } ^{33}\text{P in sample x 25 mL digest}}{\text{Specific activity of P in preplant band x 4 mL digest}}$$

The proportion of the total P coming from the preplant bands and seed bands, respectively, was calculated as follows:

$$\%\ P\ \text{from preplant band} = \frac{\text{mg P from preplant band in sample}}{\text{mg total P in sample}} \times 100$$

$$\%\ P\ \text{from seed band} = \frac{\text{mg P from seed band in sample}}{\text{mg total P in sample}} \times 100$$

Statistical analyses.

All the data were analyzed by the Statistical Analysis System (Helwig and Council (ed), 1979), available at the Computing Center at Kansas State University.

In the field studies, when samples from areas A, B, and C were collected only in the subplots of one the main plot treatments, the variables measured in those areas were analyzed as coming from a split plot design. In this design, seed band rates were the main plot treatments and areas within the row (A, B, C) the subplot treatments. When samples from areas A, B, and C were collected in all the subplots, the variables measured in those areas were analyzed as coming from a split-split plot design. In this design, preplant band rates were the main plot treatments, seed-band rates the subplot treatments, and areas within the row (A, B, C) the sub-subplot treatments.

When analyzing the results of the greenhouse study it was found that most of the measured variables had not been affected by the rows and columns in which the boxes had been arranged. For those variables, the sums of squares of rows and columns were pooled into the sums of squares for the main plot error in order to obtain more degrees of freedom for the error term.

RESULTS AND DISCUSSION

Field Studies

The 1980-81 and 1981-82 crop years were very different in climatic conditions. The 1980-81 year was warmer and drier than normal, especially early in the spring, whereas the 1981-82 year was about normal in temperatures but higher than normal in rainfall (Appendix Figures A-1, A-2, and A-3). These different climatic conditions provided two contrasting environments for the field studies, one with limited water supply, especially early in the spring, and another with non-limiting water supply.

1980-81 Field study in Dickinson Co.

An error caused this study to be drilled with a seeding rate double than intended (Table 3). This may have affected the results obtained at the different tissue samplings and at harvest. Tiller counts and spike samplings were conducted in row areas thinned to a normal population (246 plants/m^2), and thus were not affected by the high seeding rate.

When the study was planted (6 October) the seedbed was too dry to allow immediate germination and emergence. For that reason, the wheat did not emerge until after a rain received on 16 October.

Approximately one month after emergence (22 November), the subplots with the two highest rates of seed-banded fertilizer (6-10, and 12-20 kg/ha of N and P, respectively) were visually superior to the others in terms of wheat growth. At that time, row areas over preplant bands were showing slightly more growth than row areas between preplant bands.

Tiller counts

As described in Materials and Methods, the tiller counts in this study were made only in the main plots with the highest rate of preplant-banded fertilizer (112 and 20 kg/ha of N and P, respectively).

The results of the counts made on 5 December are summarized in Table 6. The analysis of variance performed on these results is given in Appendix Table A-2. There were significant effects of seed-band rate and row area location, but there was no significant interaction between the two factors. The number of tillers/m^2 was significantly increased by two highest rates of seed-banded fertilizer, compared to the control. Row areas over (A) or immediately to the side of a preplant band (B) had significantly more tillers/m^2 than row areas midway between preplant bands (C). These differences between row areas were visually apparent as a "wavy effect" in the field.

By the second tiller count (28 February), the number of tillers/m^2 had doubled, and the visual "wavy effect" had increased (Table 6). As in the previous tiller count, there were significant effects of seed band rate and row area location, but there was no significant interaction between the two factors (Appendix Table A-2). As before, the number of tillers/m^2 was significantly increased by the two highest rates of seed-banded fertilizer, when compared to the control. There were large differences between row

Table 6. Effects of seed band rate of N and P, and row area location on tillering of winter wheat for two counting dates (Dickinson Co.).

Seed band		5 December 1980				28 February 1981			
		Row area*				Row area*			
N	P	A	B	C	$\bar{x}$	A	B	C	$\bar{x}$
-kg/ha-		--------tillers/m^2--------				---------tillers/m^2-----------			
0	0	713	756	664	711 b	1605	1488	1076	1390 b
1.5	2.5	726	720	640	695 b	1525	1427	1138	1361 b
3	5	800	658	640	699 b	1802	1470	1181	1484 b
6	10	873	843	750	822 a	2171	1765	1365	1767 a
12	20	947	836	750	845 a	2251	1808	1538	1866 a
	$\bar{x}$	812 a+	763 a	689 b		1871 a	1592 b	1260 c	

+ Means followed by the same letter within a row or column are not significantly different according to pairwise comparisons using Fisher's L.S.D. at the 0.05 level of probability.

* A = 11.5 cm of row centered over a preplant band

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

areas, with those areas over preplant bands having almost one and a half more tillers/m^2 than row areas midway between preplant bands.

Tissue samplings.

Tissue samples were taken in all the subplots of the experiment. The results of the sampling conducted on 14 March are presented in Table 7. The analysis of variance of these results (Appendix Table A-3) indicates that dry matter yields were significantly affected by seed band rate and row area location but not by preplant rate, and that there were no significant interactions among the three factors. As observed for the number of tillers/m^2, significant increases in dry matter yield were only obtained with the two highest rates of seed-banded fertilizer (Table 8). On the average, row areas over preplant bands had almost two and a half times more dry matter than row areas midway between preplant bands. This produced a very marked "wavy effect" in the field.

There was a significant seed band rate by row area interaction for the concentrations of N and P in the tissue. The addition of seed-banded fertilizer produced a larger increase in the concentration of N and P in plants growing between preplant bands than in plants growing over preplant bands (Table 9). The addition of seed-banded fertilizer, however, did not eliminate the differences in nutrient composition between row areas.

Table 7. Effects of preplant band and seed band rates of N and P, and row area location on dry matter yield and tissue composition of winter wheat (Dickinson Co., 14 March 1981).

Preplant band		Seed band		Row area*			Row area*			Row area*		
N	P	N	P	A	B	C	A	B	C	A	B	C
----kg/ha----		--kg/ha--		-Dry matter yield (g/m^2)			---Tissue N (%)---			----Tissue P (%)------		
112	0	0	0	170	81	65	4.26	3.73	3.75	0.26	0.21	0.20
		1.5	2.5	194	108	76	4.19	4.15	3.90	0.26	0.24	0.21
		3	5	161	84	69	4.30	4.19	3.92	0.26	0.24	0.21
		6	10	199	113	90	4.15	4.02	3.97	0.26	0.25	0.23
		12	20	213	141	120	4.26	4.31	4.05	0.30	0.29	0.27
112	10	0	0	193	125	77	4.32	4.14	3.87	0.33	0.30	0.22
		1.5	2.5	214	106	79	4.39	4.37	4.03	0.33	0.29	0.24
		3	5	208	132	77	4.49	4.25	4.05	0.32	0.29	0.23
		6	10	216	123	91	4.29	4.25	3.96	0.32	0.28	0.24
		12	20	215	153	117	4.33	4.20	4.20	0.35	0.29	0.28
112	20	0	0	178	103	59	4.40	4.25	3.78	0.35	0.29	0.21
		1.5	2.5	193	105	76	4.47	4.34	3.91	0.35	0.30	0.23
		3	5	202	119	76	4.40	4.17	3.99	0.34	0.29	0.21
		6	10	241	119	81	4.53	4.35	4.17	0.36	0.30	0.25
		12	20	203	134	103	4.45	4.46	4.15	0.35	0.33	0.27

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 8. Main effects of seed band rate of N and P and row area location on dry matter yield of winter wheat (Dickinson Co., 14 March 1981).

Seed band N	Seed band P	Dry matter yield
-------kg/ha-------		------g/m^2------
0	0	117 c[+]
1.5	2.5	128 c
3	5	125 c
6	10	142 b
12	20	155 a
Row area*		
A		200 a
B		116 b
C		84 c

[+] Means followed by the same letter are not significantly different according to pairwise comparisons using Fisher's L.S.D. at the 0.05 level of probability.

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 9. Effects of band rate of N and P and row area location on winter wheat tissue composition, averaged over preplant band rates (Dickinson Co., 14 March 1981).

Seed band		Row area*		
N	P	A	B	C
------kg/ha------		--------Tissue N (%)--------		
0	0	4.32	4.04	3.80
1.5	2.5	4.35	4.28	3.94
3	5	4.40	4.20	3.98
6	10	4.32	4.21	4.04
12	20	4.35	4.32	4.13
------kg/ha------		--------Tissue P (%)--------		
0	0	0.31	0.27	0.21
1.5	2.5	0.31	0.28	0.22
3	5	0.31	0.27	0.22
6	10	0.31	0.28	0.24
12	20	0.33	0.30	0.27

L.S.D. 0.05:	Tissue N (%)	Tissue P (%)
between row areas within a seed band rate	0.11	0.01
between seed band rates	0.15	0.02

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

There was a significant preplant rate by row area interaction for tissue P concentration. An increase in the rate of P in the preplant band produced a larger increase in tissue P concentration in plants growing over preplant bands than in those growing between preplant bands (Table 10).

The dry matter yields per hectare calculated from the dry matter yields in the three row areas sampled (A, B, C) are presented in Table 11. The corresponding analysis of variance can be found in Appendix Table A-4. Dry matter yields per hectare were significantly affected by seed band rate, but not by preplant rate. The two highest rates of seed-banded fertilizer produced significant increases in dry matter yield when compared to the control.

The results of the sampling conducted at anthesis (2 May) are presented in Table 12; the corresponding analyses of variance can be found in Appendix Table A-5. There was a significant seed band rate by row area interaction for dry matter yield. Increasing the rate of seed-banded fertilizer significantly increased the dry matter yield in row areas midway between preplant bands, but did not affect it significantly in row areas right over or immediately to the side of a preplant band (Table 13). This was to be expected since by this stage of growth, plants growing close to the preplant band, without seed banded fertilizer, probably had absorbed enough nutrients from the preplant band to compensate for the lack of fertilizer banded with the seed; plants growing midway between preplant bands, on the other hand, probably had not been able to do so. The highest rate of seed-banded fertilizer decreased

Table 10. Effects of preplant band rate of N and P and row area location on winter wheat tissue P concentration, averaged over seed band rates (Dickinson Co., 14 March 1981).

Preplant Rate		Row area*		
N	P	A	B	C
---------kg/ha----------		-------Tissue P (%)--------		
112	0	0.27	0.25	0.22
112	10	0.33	0.29	0.24
112	20	0.35	0.31	0.23

<u>L.S.D. 0.05</u>

between row areas within a preplant rate	0.01
between preplant rates	0.03

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 11. Effects of preplant band and seed band rates of N and P on dry matter yield of winter wheat (Dickinson Co., 1981).

Preplant Band N	Preplant Band P	Seed band N	Seed band P	14 March 1981	2 May 1981
-------kg/ha--------		---kg/ha---		----------kg/ha----------	
112	0	0	0	993	5348
		1.5	2.5	1218	5674
		3	5	993	5858
		6	10	1288	6655
		12	20	1537	7492
112	10	0	0	1304	7116
		1.5	2.5	1261	6424
		3	5	1371	5754
		6	10	1384	6667
		12	20	1593	6190
112	20	0	0	1110	6172
		1.5	2.5	1178	5886
		3	5	1292	5594
		6	10	1402	6630
		12	20	1436	6522
Mean Values					
Preplant band					
		112	0	1206	6206
		112	10	1383	6430
		112	20	1284	6161
Seed band					
		0	0	1136 c[+]	6212 abc
		1.5	2.5	1219 c	5995 bc
		3	5	1219 c	5736 c
		6	10	1358 b	6651 ab
		12	20	1522 a	6735 ab

[+] Means followed by the same letter within a column are not significantly different according to pairwise comparisons using Fisher's L.S.D. at the 0.05 level of probability.

Table 12. Effects of preplant band and seed band rates of N and P and row area location on dry matter yield and tissue composition of winter wheat (Dickinson Co., 2 May 1981).

Preplant band		Seed band		Row area*			Row area*			Row area*		
N	P	N	P	A	B	C	A	B	C	A	B	C
------kg/ha-------		---kg/ha---		--Dry matter yield (g/m^2)--			---Tissue N (%)---			----Tissue P (%)-----		
112	0	0	0	678	502	458	1.65	1.65	1.77	0.15	0.16	0.17
		1.5	2.5	643	595	437	1.74	1.55	1.55	0.14	0.15	0.16
		3	5	706	551	535	1.63	1.56	1.60	0.14	0.15	0.16
		6	10	792	667	536	1.57	1.67	1.61	0.16	0.16	0.16
		12	20	846	720	711	1.53	1.55	1.58	0.17	0.18	0.18
112	10	0	0	948	715	469	1.53	1.77	1.70	0.17	0.18	0.20
		1.5	2.5	1023	590	365	1.35	1.46	1.58	0.16	0.17	0.17
		3	5	793	565	379	1.57	1.55	1.65	0.16	0.17	0.18
		6	10	849	658	502	1.33	1.40	1.47	0.17	0.17	0.18
		12	20	668	645	519	1.54	1.57	1.62	0.19	0.20	0.19
112	20	0	0	967	561	380	1.63	1.59	1.67	0.17	0.17	0.19
		1.5	2.5	950	524	357	1.68	1.69	1.71	0.18	0.19	0.20
		3	5	876	503	355	1.61	1.59	1.88	0.19	0.20	0.19
		6	10	849	652	499	1.65	1.59	1.49	0.18	0.18	0.18
		12	20	882	624	480	1.76	1.67	1.63	0.20	0.19	0.19

*

A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 13. Effects of preplant band rate of N and P and row area location, and effects of seed band rate of N and P and row area location on dry matter yield of winter wheat, averaged over seed band rates and preplant band rates, respectively (Dickinson Co.)

Preplant band		Row area*		
N	P	A	B	C
------kg/ha------		-----Dry matter yield (g/m^2)--------		
112	0	733	607	535
112	10	856	634	447
112	20	905	573	414

L.S.D. 0.05

between row areas within a preplant rate	76
between preplant rates	127

Seed band		Row area*		
N	P	A	B	C
------kg/ha------		-----Dry matter yield (g/m^2)--------		
0	0	864	592	435
1.5	2.5	872	570	386
3	5	792	540	423
6	10	830	660	513
12	20	799	663	570

L.S.D. 0.05

between row areas within a seed band rate	98
between seed band rates	118

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

the "wavy effect" since it increased wheat growth between preplant bands without significantly affecting it over preplant bands. The "wavy effect" was still present, however, as indicated by the differences in dry matter yield between row areas of the highest seed band rate.

There was a significant preplant rate by row area interaction for matter yield. Increasing the rate of P in the preplant band increased the dry matter yield in row areas over preplant bands and tended to decrease it in row areas between preplant bands (Table 13). These results would suggest the presence of a limiting factor, probably soil moisture, which was limiting the dry matter produced per unit area of land. This seems to be supported by the results obtained when the dry matter yields in the sampled row areas were used to calculate the dry matter yields per hectare (Table 11). Both, the addition of P to the preplant band, and the application of seed-banded fertilizer failed to produce significant increases in dry matter yield per hectare.

There was a significant seed band rate by row area interaction for tissue P concentration. The highest rate of seed-banded fertilizer significantly increased tissue P concentration in plants growing over preplant bands, but did not affect it significantly in plants growing midway between preplant bands, when compared to the control (Table 14). At the lower seed band rates, plants growing over preplant bands had lower tissue P concentrations than plants growing between preplant bands. These results are reversed to those of the earlier sampling date, and are probably due to a

Table 14. Effects of seed band rate of N and P and row area location on winter wheat tissue P concentration, averaged over preplant rates (Dickinson Co., 2 May 1981).

Seed band		Row area*		
N	P	A	B	C
-----kg/ha------		----------Tissue P (%)----------		
0	0	0.16	0.17	0.18
1.5	2.5	0.16	0.17	0.18
3	5	0.16	0.17	0.18
6	10	0.17	0.17	0.17
12	20	0.19	0.19	0.19

L.S.D. 0.05:

between row areas within a seed band rate	0.01
between seed band rates	0.02

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

dilution effect caused by the extensive wheat growth observed directly over preplant bands.

Tissue N concentration was not significantly affected by any of the factors at this sampling date.

Spike sampling

The results of the spike sampling conducted just before harvest are summarized in Tables 15 and 16. The analyses of variance of these results can be found in Appendix Tables A-6 and A-7. Number of spikes/m^2 and grain yield were significantly affected by row area location, but not by seed band rate. Row areas over preplant bands had almost twice as many spikes/m^2 and yielded almost twice as much grain as row areas midway between preplant bands. This shows that the "wavy effect" was still present at harvest time. Grain composition and other grain yield components were not affected by any of the factors at this sampling date.

The percent tiller survival for each of the seed band rates in the main plots with 112 kg N/ha and 20 kg P/ha in the preplant band is presented in Table 17; the corresponding analysis of variance can be found in Appendix Table A-8. There were significant effects of seed band rate and row area location, but there was no significant interaction between the two factors. The two highest rates of seed-banded fertilizer decreased the percent tiller survival when compared to the lower seed band rates. This was due to the fact that the two highest seed band rates increased

Table 15. Effects of seed band rate of N and P and row area location on grain yield components of winter wheat (Dickinson Co., 1981).**

Seed band N	Seed band P	Row area* A	Row area* B	Row area* C
-------kg/ha-------		---------Spikes/m^2---------		
0	0	781	529	332
1.5	2.5	695	621	400
3	5	849	609	430
6	10	756	578	332
12	20	750	627	480
	$\bar{x}$	766 a[+]	593 b	395 c
		-------Kernels/spike-------		
0	0	25.3	27.3	21.0
1.5	2.5	23.0	24.7	23.3
3	5	23.5	21.5	21.3
6	10	22.5	21.5	23.0
12	20	24.7	24.0	22.7
	$\bar{x}$	23.8	23.8	22.3
		-------Kernel wt. (mg)-------		
0	0	30.4	31.3	30.6
1.5	2.5	30.1	32.0	30.7
3	5	28.9	31.1	32.5
6	10	31.2	30.7	30.8
12	20	30.3	30.7	30.5
	$\bar{x}$	30.2	31.2	31.0

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant band.

[+] Means followed by the same letter within a row are not significantly different according to pairwise comparisons using Fisher's L.S.D. at the 0.05 level of probability.

** For preplant rate 112-20 only.

Table 16. Effects of seed band rate of N and P and row area location on grain yield and grain composition of winter wheat (Dickinson Co., 1981).**

Seed band N	Seed band P	Row area* A	Row area* B	Row area* C
-------kg/ha-------		------Grain Yield (g/m^2)------		
0	0	601	450	215
1.5	2.5	493	491	295
3	5	563	415	290
6	10	523	380	234
12	20	552	451	339
	$\bar{x}$	547 a[+]	437 b	275 c
		--------Grain Protein (%)------		
0	0	14.1	13.8	14.7
1.5	2.5	14.0	13.5	13.5
3	5	12.6	12.4	12.3
6	10	14.3	14.2	13.6
12	20	14.5	13.8	14.1
	$\bar{x}$	13.9	13.5	13.6
		----------Grain P (%)----------		
0	0	0.35	0.34	0.36
1.5	2.5	0.34	0.33	0.35
3	5	0.33	0.35	0.36
6	10	0.38	0.38	0.35
12	20	0.34	0.37	0.36
	$\bar{x}$	0.35	0.35	0.36

* A = 11.5 cm of row centered over a preplant band.
B = 11.5 cm of row centered between A and C.
C = 11.5 cm of row centered between preplant bands.

[+] Means followed by the same letter within a row are not significantly different according to pairwise comparisons using Fisher's L.S.D. at the 0.05 level of probability.

** For preplant rate 112-20 only.

Table 17. Effects of seed band rate of N and P and row area location on percent tiller survival of winter wheat (Dickinson Co. 1981).**

Seed band N	Seed band P	Row area* A	Row area* B	Row area* C	$\bar{x}$
-------kg/ha-------		--Tiller survival (%)--			
0	0	48.1	35.8	31.9	38.6 ab
1.5	2.5	45.7	43.7	35.1	41.5 a
3	5	47.3	41.0	37.7	42.0 a
6	10	36.1	33.1	25.2	31.5 c
12	20	33.3	34.9	31.5	33.2 bc
	$\bar{x}$	42.1 a[+]	37.7 b	32.3 c	

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

[+] Means followed by the same letter within a row or column are not significantly different according to pairwise comparisons using Fisher's L.S.D. at the 0.05 level of probability.

** For preplant rate 112-20 only.

the number of tillers/m^2 but failed to increase the number of spikes/m^2. Row areas over preplant bands had a significantly higher percent tiller survival than row areas between preplant bands. This indicates that the relative differences between row areas were even larger at harvest time than at the time the tiller counts were made.

Grain harvest

The results obtained at harvest are presented in Table 18; the analyses of variance are given in Appendix Table A-9. There were no significant affects of preplant rate and seed band rate on grain yield and grain composition.

The lack of a significant response in grain yield to the seed-banded fertilizer could have been due to the dry and warm climate conditions that existed early in the spring (Appendix Figures A-1 and A-3). The mild temperatures (which allowed early growth) and the lack of adequate rain placed the crop under a water stress which probably limited the number of tillers that were able to produce spikes. This, in turn, may have eliminated any possible yield response to the seed-banded fertilizer. The excessive seeding rate used in this study may also have contributed to the water stress to which the crop was exposed.

The results of this study show that the increases in tillering and early dry matter production obtained with the application of seed-banded fertilizer do not necessarily result in significant increases in grain yield.

Table 18. Effects of preplant band and seed band rates of N and P on grain yield and grain composition of winter wheat (Dickinson Co., 1981).

Preplant band N	Preplant band P	Seed band N	Seed band P	Grain Yield	Grain Protein	Grain P
----kg/ha----		--kg/ha--		---kg/ha---	------%------	---%---
112	0	0	0	3063	14.3	0.34
		1.5	2.5	3158	14.2	0.33
		3	5	3414	13.4	0.33
		6	10	3313	14.6	0.36
		12	20	3389	13.9	0.35
112	10	0	0	3237	13.8	0.35
		1.5	2.5	3274	14.2	0.36
		3	5	3513	15.0	0.36
		6	10	3488	14.2	0.36
		12	20	3294	14.0	0.37
112	20	0	0	3318	14.4	0.35
		1.5	2.5	3394	14.3	0.34
		3	5	3237	14.4	0.34
		6	10	3419	13.7	0.36
		12	20	3496	13.2	0.37
Mean Values						
		Preplant band				
		112	0	3266	14.1	0.34
		112	10	3360	14.2	0.36
		112	20	3373	14.0	0.35
		Seed band				
		0	0	3205	14.2	0.35
		1.5	2.5	3273	14.3	0.34
		3	5	3389	14.3	0.34
		6	10	3407	14.2	0.36
		12	20	3394	13.7	0.36

1981-82 Field Study in Dickinson Co.

Adequate soil moisture at planting time allowed rapid germination and emergence at this site. Approximately one month after emergence (15 November) there were noticeable differences in growth between treatments. The subplots with seed-banded N and P fertilizer were visually superior to those without seed-banded fertilizer or with only N in the seed band. A slight "wavy effect" could be observed in the main plots with preplant-banded N and P fertilizer.

Plant sampling

In the 1981-82 studies, plant samples were taken in all the subplots of the experiment. The results of the sampling conducted on 27 March are summarized in Tables 19 and 20. The corresponding analyses of variance can be found in Appendix Table A-10. There was a significant preplant rate by seed band rate by row area interaction for dry matter yield, number of tillers/m^2, and tissue N concentration. In general, the application of N alone with the seed did not produce significant increases in dry matter yield, number of tillers/m^2, and N content in tissue, compared to the control. This indicates that N alone was not having an effect. As the seed band rate of P increased, a significant increase in dry matter yield and number of tillers/m^2 was obtained in all the row areas of the preplant rate 70-0, in row areas B and C of the preplant rate 70-9, and in row areas A and C of the preplant rate 70-18. These increases

Table 19. Effects of preplant band and seed band rates of N and P and row area location on dry matter yield and tillering of winter wheat (Dickinson Co., 27 March 1982).

Preplant band		Seed band		Row area*			Row area*		
N	P	N	P	A	B	C	A	B	C
----kg/ha----		--kg/ha--		-Dry matter yield (g/m^2)-			--Tillers/m^2--		
70	0	0	0	73	49	46	1719	1292	1152
		15	0	71	43	56	1751	1166	1485
		15	4.5	64	63	68	1525	1622	1704
		15	9	79	73	70	1783	1772	1676
		15	18	97	86	89	2239	2038	2027
70	9	0	0	107	62	40	2153	1643	1055
		15	0	102	72	41	2386	1783	1202
		15	4.5	118	74	53	2422	1611	1320
		15	9	105	93	52	2250	2368	1640
		15	18	107	104	81	2106	2343	1902
70	18	0	0	75	69	46	1927	1812	1327
		15	0	117	66	43	2626	1618	1256
		15	4.5	100	77	66	2397	2002	1801
		15	9	112	75	67	2379	1859	1798
		15	18	106	70	81	2512	1719	1991

L.S.D. 0.05	Dry matter yield	Tillers/m^2
between row areas within a seed band rate and a preplant rate	20	424
between seed band rates within a row area and a preplant rate	24	440

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 20. Effects of preplant band and seed band rates of N and P and row area location on winter wheat tissue composition (Dickinson Co., 27 March 1982).

Preplant band		Seed band		Row area*			Row area*		
N	P	N	P	A	B	C	A	B	C
----kg/ha----		--kg/ha--		--Tissue N (%)---			--Tissue P (%)---		
70	0	0	0	3.17	3.11	2.98	0.16	0.15	0.14
		15	0	3.29	3.19	3.05	0.18	0.17	0.15
		15	4.5	3.19	3.41	3.22	0.19	0.19	0.18
		15	9	3.64	3.65	3.53	0.22	0.21	0.20
		15	18	3.79	3.50	3.45	0.28	0.25	0.25
70	9	0	0	3.65	3.58	3.07	0.27	0.22	0.17
		15	0	3.94	3.72	3.16	0.31	0.25	0.17
		15	4.5	3.78	3.57	3.37	0.31	0.23	0.20
		15	9	4.02	3.85	3.51	0.31	0.29	0.22
		15	18	3.33	3.39	3.39	0.29	0.27	0.25
70	18	0	0	4.11	3.83	3.55	0.37	0.31	0.22
		15	0	3.96	3.66	3.47	0.36	0.26	0.21
		15	4.5	4.55	4.10	3.63	0.39	0.33	0.22
		15	9	4.23	4.06	3.68	0.36	0.30	0.25
		15	18	3.92	3.72	3.65	0.39	0.32	0.29

L.S.D. 0.05	Tissue N	Tissue P
between row areas within a seed band rate and a preplant rate	0.28	0.03
between seed band rates within a row area and a preplant rate	0.41	0.05

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

in wheat growth tended to reduce the "wavy effect", particularly in the main plots with only N in the preplant band. Increasing the rate of seed-banded P fertilizer increased tissue N concentration in all the row areas of the preplant rate 70-0 and in row areas C of the preplant rate 70-9, and had little effect in other row areas . There was also a lower tissue N concentration as the distance from the preplant band increased.

There was a significant preplant rate by row area interaction for dry matter yield, number of tillers/m^2, and tissue N and P concentrations. The results presented in Table 21 show that increasing the rate of preplant-banded P produced significant increases in dry matter yield and number of tillers/m^2 in row areas over preplant bands, but either reduced or did not affect these variables in row areas midway between preplant bands. Similarly, an increase in the rate of P in the preplant band produced larger increases in the concentrations of N and P in plants growing over preplant bands than in those growing between preplant bands. This indicates that the fertilizer P applied in the preplant band provided a better supply of P to plants growing close to the preplant band than to those growing midway between preplant bands.

The dry matter yields per hectare calculated from the results of the detailed plant sampling are presented in Table 22; the analysis of variance of these results can be found in Appendix Table A-11. Dry matter yields per hectare were significantly affected by seed band rate but not by preplant rate. The main effects of the seed band rates show that while the application of

Table 21. Effects of preplant band rate of N and P and row area location on dry matter yield, tillering and tissue composition of winter wheat, averaged over seed band rates (Dickinson Co., 27 March 1982).

Preplant Rate		Row area*		
N	P	A	B	C
---------kg/ha---------		-Dry matter yield (g/m^2)-		
70	0	77	63	66
70	9	108	81	53
70	18	102	71	60
		---------Tillers/m^2-------		
70	0	1803	1578	1609
70	9	2262	1950	1424
70	18	2368	1802	1635
		-------Tissue N (%)-------		
70	0	3.42	3.37	3.25
70	9	3.74	3.62	3.30
70	18	4.15	3.87	3.60
		--------Tissue P (%)---------		
70	0	0.21	0.19	0.18
70	9	0.30	0.25	0.20
70	18	0.37	0.30	0.24

L.S.D. 0.05:	Dry matter yield	Tillers/m^2	Tissue N	Tissue P
between row areas within a preplant rate	9	190	0.13	0.01
between preplant rates	16	176	0.22	0.03

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 22. Effect of preplant band and seed band rates of N and P on dry matter yield of winter wheat (Dickinson Co., 27 March 1982).

Preplant band N	Preplant band P	Seed band N	Seed band P	Dry matter yield
----kg/ha----		--kg/ha--		-----kg/ha------
70	0	0	0	549
		15	0	536
		15	4.5	652
		15	9	746
		15	18	904
70	9	0	0	682
		15	0	727
		15	4.5	804
		15	9	867
		15	18	999
70	18	0	0	650
		15	0	737
		15	4.5	808
		15	9	829
		15	18	827
Mean values				
Preplant band				
70		0		678
70		9		816
70		18		770
Seed band				
0		0		627 d +
15		0		667 cd
15		4.5		755 bc
15		9		814 ab
15		18		911 a

+ Means followed by the same letter are not significantly different according to pairwise comparisons using Fisher's L.S.D. at the 0.05 level of probability.

N alone did not have any significant effect, the application of increasing rates of P with N produced a significant increase in dry matter yield, when compared to the control.

Spike sampling

The results of the spike sampling conducted just before harvest are presented in Tables 23 and 24; the analyses of variance are given in Appendix Tables A-12 and A-13. There was a significant seed band rate by row area interaction for the number of spikes/m^2, number of kernels/spike, mean kernel weight, and grain yield. The use of N alone in the seed-banded fertilizer showed a trend toward increasing the number of spikes/m^2 and grain yield in all row areas, but these increases did not reach statistical significance (Table 25). However, the application of N alone significantly increased the number of kernels/spike and significantly reduced the mean kernel weight in row areas over preplant bands. The use of 9 or 18 kg P/ha with N in the seed-banded fertilizer significantly increased the number of spikes/m^2 and grain yield in row areas midway between preplant bands without having major effects on the other row areas. The grain yield increases obtained in row areas midway between preplant bands were mainly due to the increases in the number of spikes/m^2.

There was a significant preplant rate by row area interaction for the number of spikes/m^2, grain yield, and grain protein and P concentrations. Increasing the rate of P in the preplant band from 0 to 9 and from 0 to 18 kg P/ha significantly increased the number of spikes/m^2 and grain yield in row areas over preplant bands, but either reduced or did not affect these

Table 23. Effects of preplant band and seed band rates of N and P and row area location on grain yield and grain composition of winter wheat (Dickinson Co., 1982).

Preplant band		Seed band		Row area*			Row area*			Row area*		
N	P	N	P	A	B	C	A	B	C	A	B	C
----kg/ha----		--kg/ha--		-Grain yield (g/m^2)-			-Grain Protein (%)-			---Grain P (%)----		
70	0	0	0	426	377	361	10.4	10.2	9.9	0.29	0.31	0.29
		15	0	446	391	297	10.6	10.4	9.9	0.31	0.33	0.33
		15	4.5	329	380	292	9.9	9.9	9.8	0.33	0.34	0.33
		15	9	463	425	413	9.5	9.7	9.7	0.29	0.32	0.30
		15	18	461	373	366	9.6	9.8	9.5	0.33	0.35	0.30
70	9	0	0	683	340	190	9.3	9.6	9.7	0.30	0.34	0.35
		15	0	681	446	241	9.9	9.6	10.0	0.28	0.27	0.33
		15	4.5	532	385	322	9.3	9.3	9.3	0.33	0.31	0.31
		15	9	617	386	349	9.2	9.4	9.5	0.32	0.31	0.34
		15	18	529	431	326	9.2	9.3	9.7	0.34	0.33	0.34
70	18	0	0	607	297	234	8.9	9.4	9.5	0.33	0.37	0.37
		15	0	720	356	269	9.7	9.5	9.9	0.34	0.31	0.33
		15	4.5	730	363	389	9.5	9.6	9.8	0.34	0.33	0.34
		15	9	724	357	358	9.1	9.3	9.8	0.33	0.34	0.45
		15	18	629	430	364	9.4	9.3	9.8	0.35	0.34	0.37

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 24. Effects of preplant band and seed band rates of N and P and row area location on grain yield components of winter wheat (Dickinson Co., 1982).

Preplant band		Seed band		Row area*			Row area*			Row area*		
N	P	N	P	A	B	C	A	B	C	A	B	C
------kg/ha------		----kg/ha----		----Spikes/m^2----			--Kernels/spike--			-Kernel wt (mg)--		
70	0	0	0	670	610	610	22.0	22.6	21.9	27.3	27.0	27.0
		15	0	718	617	484	23.8	23.2	22.2	26.2	27.5	26.9
		15	4.5	567	613	538	21.2	23.0	21.1	27.0	26.7	25.9
		15	9	743	721	696	22.1	22.1	21.8	28.2	26.9	27.3
		15	18	822	628	631	19.4	20.7	20.6	28.8	28.5	28.1
70	9	0	0	1091	542	344	23.3	23.4	21.0	27.0	26.7	26.5
		15	0	1055	685	430	25.7	23.7	22.0	25.3	27.5	25.5
		15	4.5	886	649	538	21.7	20.9	21.2	27.7	28.5	28.1
		15	9	1033	628	596	21.0	22.9	20.7	28.5	26.9	28.3
		15	18	854	707	556	21.2	21.3	21.9	29.4	28.7	26.4
70	18	0	0	976	499	366	21.4	20.7	21.5	29.0	27.6	29.4
		15	0	1116	592	499	23.4	21.2	20.0	27.7	28.2	26.8
		15	4.5	1137	592	649	22.9	22.3	21.8	28.0	27.4	27.5
		15	9	1151	610	577	20.9	20.0	21.3	30.1	29.4	29.3
		15	18	994	718	624	22.2	20.1	22.1	28.3	29.8	25.9

* A = 11.5 of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 25. Effects of seed band rate of N and P, and row area location on grain yield and grain yield components of winter wheat, averaged over preplant rates (Dickinson Co., 1982).

Seed band N	Seed band P	Row area* A	Row area* B	Row area* C
------kg/ha------		------Grain yield (g/m^2)----------		
0	0	572	338	261
15	0	616	397	269
15	4.5	530	376	334
15	9	602	389	373
15	18	540	411	352
		------------Spikes/m^2------------		
0	0	922	550	440
15	0	963	631	471
15	4.5	863	618	575
15	9	976	653	623
15	18	889	684	604
		------------Kernels/spike---------		
0	0	22.2	22.2	21.5
15	0	24.3	22.7	21.4
15	4.5	21.9	22.1	21.3
15	9	21.3	21.7	21.3
15	18	21.0	20.7	21.5
		------------Kernel wt.(mg)--------		
0	0	27.8	27.1	27.6
15	0	26.4	27.7	26.4
15	4.5	27.6	27.5	27.2
15	9	28.9	27.7	28.3
15	18	28.8	29.0	26.8

L.S.D. 0.05

	Grain yield	Spikes/ m^2	Kernels/ spike	Kernel wt.
between row areas within a seed band rate	66	103	1.3	1.3
between seed band rates	79	110	1.8	1.3

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

variables in row areas midway between preplant bands (Table 26). These effects are similar to the effects of increasing the rate of P in the preplant band on the number of tillers/m^2 (Table 21). The addition of P to the preplant band significantly decreased the grain protein concentration in row areas over preplant bands without affecting it in row areas midway between preplant bands. This is probably due to a dilution effect caused by the increase in grain yield observed in row areas over preplant bands. This dilution effect in row areas over preplant bands may also be the reason why increasing the rate of P in the preplant band produced lower increases in gain P concentration in row areas over preplant bands than in row areas midway between preplant bands.

The percent tiller survival for the different treatments is presented in Table 27; the analysis of variance is given in Appendix Table A-14. Tiller survival was significantly affected by row area location only. As observed in the study conducted in Dickinson Co. during 1980-81, row areas over preplant bands had higher percent tiller survival than row areas between preplant bands.

Grain harvest

The results obtained at harvest are presented in Table 28, the corresponding analyses of variance can be found in Appendix Table A-11. Grain yields and grain protein concentration were significantly affected by seed band rate, but not by preplant rate. The use of N alone in the seed-banded fertilizer produced

Table 26. Effects of preplant band rate of N and P and row area location on grain yield, spike density, and grain protein and P concentrations of winter wheat, averaged over seed band rates (Dickinson Co., 1982)

Preplant band		Row area*		
N	P	A	B	C
------kg/ha------		---------Grain yield (g/m^2)---------		
70	0	425	389	346
70	9	609	397	285
70	18	682	360	322
		--------------Spikes/m^2-------------		
70	0	710	638	592
70	9	984	642	493
70	18	1075	602	543
		--------Grain protein (%)-----------		
70	0	10.0	10.0	9.7
70	9	9.4	9.5	9.7
70	18	9.3	9.4	9.8
		-----------Grain P (%)-------------		
70	0	0.31	0.33	0.31
70	9	0.31	0.31	0.34
70	18	0.34	0.34	0.37

L.S.D. 0.05	Grain yield	Spikes/m^2	Grain protein	Grain P
between row areas within a preplant rate	52	80	0.2	0.03
between preplant rates	56	91	0.6	0.03

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 27. Effects of preplant band and seed band rates of N and P and row area location on percent tiller survival of winter wheat (Dickinson Co., 1982).

Preplant band		Seed band		Row area*		
N	P	N	P	A	B	C
----kg/ha----		--kg/ha--		----Tiller survival (%)----		
70	0	0	0	43.0	49.5	54.5
		15	0	41.6	55.7	32.7
		15	4.5	37.5	38.4	31.8
		15	9	41.8	41.7	45.5
		15	18	36.5	31.6	31.4
70	9	0	0	51.4	34.4	32.6
		15	0	46.1	39.1	37.3
		15	4.5	37.1	40.7	40.4
		15	9	49.7	26.4	37.1
		15	18	41.6	30.2	29.7
70	18	0	0	52.4	28.1	27.6
		15	0	42.5	38.1	41.7
		15	4.5	47.8	30.2	36.9
		15	9	48.2	33.4	32.2
		15	18	40.9	43.0	31.3
	$\bar{x}$			43.9 a[+]	37.4 b	36.2 c

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

+ Means followed by the same letter are not significantly different according to pairwise comparisons using Fisher's L.S.D. at the 0.05 level of probability.

Table 28. Effect of preplant band and seed band rates of N and P on grain yield and grain composition of winter wheat (Dickinson Co., 1982).

Preplant band N	Preplant band P	Seed band N	Seed band P	Grain Yield	Grain Protein	Grain P
----kg/ha----		--kg/ha--		---kg/ha---	------%------	---%---
70	0	0	0	3193	10.5	0.31
		15	0	3124	11.1	0.31
		15	4.5	3466	10.3	0.32
		15	9	3301	10.5	0.38
		15	18	3783	9.7	0.29
70	9	0	0	3073	10.6	0.33
		15	0	3529	11.0	0.32
		15	4.5	3675	10.4	0.31
		15	9	3757	10.0	0.29
		15	18	3707	9.8	0.32
70	18	0	0	3359	9.8	0.30
		15	0	3789	10.1	0.29
		15	4.5	3574	10.4	0.37
		15	9	3713	10.3	0.30
		15	18	3567	9.8	0.34
Mean values						
	Preplant band					
		70	0	3373	10.4	0.32
		70	9	3548	10.4	0.31
		70	18	3600	10.1	0.32
	Seed band					
		0	0	3208 b+	10.3 a	0.31
		15	0	3481 a	10.7 a	0.31
		15	4.5	3572 a	10.4 a	0.33
		15	9	3591 a	10.3 a	0.32
		15	18	3686 a	9.8 b	0.32

+ Means followed by the same letter within a column are not significantly different according to pairwise comparisons using Fisher's L.S.D. at the 0.05 level of probability.

a significant increase in grain yield over the control. The use of N and P in the seed-banded fertilizer also increased grain yields over the control but not over the treatment with N alone in the seed-banded fertilizer. The concentration of protein in the grain decreased as grain yields increased.

Since there was no grain yield response to preplant-banded P, it was not possible to determine if the favorable effects of seed-banded fertilizer on grain yield could be additive to the effects of preplant banded P.

1981-82 Field Study in Marion Co.

Excellent seedbed conditions and adequate soil moisture allowed rapid germination and emergence. Late in the fall, the subplots that received seed-banded N and P fertilizer were visually superior to those without seed-banded fertilizer or with only N in the seed band, in terms of wheat growth. At that time there were no noticeable differences in growth between plants growing over preplant bands and plants growing between preplant bands.

Plant sampling

The results of the sampling conducted on 3 April are presented in Tables 29 and 30; the analyses of variance of these results are given in Appendix Table A-15. The seed band rate had significant effects on dry matter yield, number of tillers/m^2, and tissue N and P concentrations, but showed no interaction in these

Table 29. Effects of preplant band and seed band rates of N and P, and row area location on dry matter yield and tillering of winter wheat (Marion Co., 3 April 1982).

Preplant band		Seed band		Row area*			Row area*		
N	P	N	P	A	B	C	A	B	C
----kg/ha-----		--kg/ha--		--Dry matter yield (g/m^2)--			-----Tillers/m^2------		
70	0	0	0	99	86	85	1539	1539	1467
		15	0	81	92	90	1396	1546	1485
		15	4.5	102	93	113	1521	1478	1708
		15	9	132	147	111	1894	1916	1708
		15	18	179	156	161	2024	1866	2131
70	9	0	0	209	173	96	2314	2024	1496
		15	0	197	174	127	2382	2031	1622
		15	4.5	212	193	116	2235	2217	1575
		15	9	187	188	183	2016	2056	2099
		15	18	250	192	162	2511	2135	1783
70	18	0	0	181	110	99	2207	1622	1589
		15	0	148	118	93	2102	1622	1510
		15	4.5	161	139	101	2131	1769	1446
		15	9	152	122	121	2131	1557	1615
		15	18	162	125	140	2167	1801	1859

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 30. Effects of preplant band and seed band rates of N and P and row area location on winter wheat tissue composition (Marion Co., 3 April 1982).

Preplant band		Seed band		Row area*			Row area*		
N	P	N	P	A	B	C	A	B	C
----kg/ha----		--kg/ha--		------Tissue N (%)-------			------Tissue P (%)-------		
70	0	0	0	3.75	3.77	3.71	0.21	0.23	0.21
		15	0	3.96	3.85	3.76	0.22	0.21	0.22
		15	4.5	3.83	3.87	3.74	0.22	0.22	0.21
		15	9	4.00	3.86	4.03	0.26	0.26	0.26
		15	18	3.92	3.97	3.97	0.27	0.26	0.27
70	9	0	0	3.87	3.79	3.61	0.23	0.22	0.20
		15	0	4.14	3.95	3.86	0.27	0.25	0.22
		15	4.5	3.87	3.89	3.82	0.25	0.25	0.22
		15	9	4.23	4.15	3.99	0.30	0.28	0.25
		15	18	4.07	4.07	4.04	0.29	0.28	0.29
70	18	0	0	4.39	4.07	4.00	0.32	0.30	0.25
		15	0	4.18	4.38	4.19	0.34	0.30	0.28
		15	4.5	4.17	4.08	4.14	0.39	0.35	0.27
		15	9	4.08	4.43	4.18	0.42	0.33	0.31
		15	18	4.32	4.13	4.19	0.43	0.41	0.36

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

effects with preplant rate or row area. The use of N alone in the seed-banded fertilizer significantly increased tissue N and P concentrations, but had no significant effect on dry matter yield and number of tillers/m^2 (Table 31). Increasing the rate of P in the seed-banded fertilizer showed a trend toward increasing dry matter yield and number of tillers/m^2, but those increases reached statistical significance only with the two highest rates of P for dry matter yield, and only with the highest rate of P for the number of tillers/m^2. Tissue P concentration was significantly increased by the two highest rates of seed-banded P.

There was a significant preplant rate by row area interaction for dry matter yield, number of tillers/m^2 and tissue P concentration. When only N was applied in the preplant band, there were no significant differences between row areas for any of the variables (Table 32). This was probably due to the initially high mineral N level in the soil. The addition of P to the preplant band significantly increased the dry matter yield and number of tillers/m^2 in row areas over preplant bands, but had no significant effect on these variables in row areas midway between preplant bands. This produced a marked "wavy effect" in the main plots with preplant-banded N and P fertilizer. The addition of P to the preplant band produced a larger increase in tissue P concentration in plants growing over preplant bands than in plants growing between preplant bands. This also was observed in the previously discussed studies.

The dry matter yields per hectare calculated from the results of the detailed plant sampling are presented in Table 33; the

Table 31. Main effects of seed band rate of N and P on dry matter yield, tillering and tissue composition of winter wheat in sampled row areas (Marion Co., 3 April 1982).

Seed band N	Seed band P	Dry matter yield	Tillering	Tissue N	Tissue P
---kg/ha---		---g/m^2---	-tillers/m^2-	---%----	---%----
0	0	127 c+	1755 b	3.88 b	0.24 d
15	0	125 c	1744 b	4.03 a	0.26 c
15	4.5	137 bc	1787 b	3.94 b	0.26 c
15	9	149 b	1888 ab	4.10 a	0.30 b
15	18	170 a	2031 a	4.08 a	0.32 a

+ Means followed by the same letter within a column are not significantly different according to pairwise comparisons using Fisher's L.S.D. at the 0.05 level of probability.

Table 32. Effects of preplant band rate of N and P and row area location on dry matter yield, tillering and tissue P concentration of winter wheat, averaged over seed band rates (Marion Co., 3 April 1982).

Preplant rate		Row area*		
N	P	A	B	C
kg/ha		Dry matter yield (g/m^2)		
70	0	119	115	112
70	9	211	184	137
70	18	161	123	111
		Tillers/m^2		
70	0	1675	1670	1700
70	9	2292	2092	1715
70	18	2148	1674	1604
		Tissue P (%)		
70	0	0.24	0.24	0.23
70	9	0.27	0.25	0.24
70	18	0.38	0.34	0.29

L.S.D. 0.05	Dry matter yield	Tillers/m^2	Tissue P
between row areas within a preplant rate	18	190	0.01
between preplant rates	27	222	0.05

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 33. Effects of preplant band and seed band rates of N and P on dry matter yield of winter wheat (Marion Co., 3 April 1982).

Preplant band N	Preplant band P	Seed band N	Seed band P	Dry matter
----kg/ha----		---kg/ha---		--kg/ha---
70	0	0	0	903
		15	0	897
		15	4.5	1010
		15	9	1357
		15	18	1643
70	9	0	0	1647
		15	0	1698
		15	4.5	1803
		15	9	1884
		15	18	2009
70	18	0	0	1264
		15	0	1208
		15	4.5	1364
		15	9	1309
		15	18	1394
Mean values:				
	Preplant band			
		70	0	1162 b+
		70	9	1808 a
		70	18	1308 b
	Seed band			
		0	0	1271 c
		15	0	1268 c
		15	4.5	1392 bc
		15	9	1516 ab
		15	18	1682 a

+ Means followed by the same letter are not significantly different according to pairwise comparisons using Fisher's L.S.D. at the 0.05 level of probability.

analysis of variance can be found in Appendix Table A-16. There were significant effects of preplant rate and seed band rate, but there was no significant interaction between the two factors. Increasing the rate of P in the preplant band from 0 to 9 kg P/ha produced a significant increase in dry matter yield, but increasing the rate from 0 to 18 kg P/ha produced an increase which was not statistically significant. The use of N alone in the seed-banded fertilizer did not have any significant effect on dry matter yield, but the use of 9 or 18 kg P/ha with N significantly increased the dry matter yields per hectare.

Spike sampling

The spike sampling conducted just before harvest was complicated by the fact that in many of the subplots lodging occurred. For that reason, only two of the four replications were sampled. The results obtained are presented in Tables 34 and 35; the corresponding analyses of variance can be found in Appendix Tables A-17 and A-18.

The main effects of the seed-banded fertilizer on grain yields and grain yield components are presented in Table 36. These effects were not significant at the 0.05 level, but are presented because they show trends that provide reasonable explanations for the results observed. The effect of seed band rate on the number of spikes/m^2 and mean kernel weight was significant at the 0.10 level of probability.

Table 34. Effects of preplant band and seed band rates of N and P and row area location on grain yield components of winter wheat (Marion Co., 1982).

Preplant band		Seed band		Row area*			Row area*			Row area*		
N	P	N	P	A	B	C	A	B	C	A	B	C
----kg/ha----		---kg/ha---		----Spikes/m^2----			--Kernels/spike---			--Kernel wt. (mg)--		
70	0	0	0	667	538	739	25.7	24.4	24.8	21.2	19.7	21.3
		15	0	868	552	574	24.8	24.3	27.1	20.5	18.1	19.3
		15	4.5	804	739	739	26.2	27.3	26.3	20.7	19.4	20.3
		15	9	840	761	739	24.8	24.3	25.7	18.1	18.2	17.7
		15	18	682	818	689	27.5	23.8	23.1	16.9	19.0	18.8
70	9	0	0	983	689	438	27.1	27.7	25.0	19.4	20.1	19.8
		15	0	1026	746	883	25.9	27.2	25.1	17.0	17.7	17.9
		15	4.5	1327	660	588	26.4	27.4	25.4	18.0	17.1	19.3
		15	9	1155	581	646	25.1	26.2	24.3	16.6	15.5	15.9
		15	18	890	775	674	25.6	25.9	28.4	16.8	17.4	17.5
70	18	0	0	861	646	789	26.9	26.2	25.1	17.8	18.7	18.3
		15	0	926	481	660	31.0	28.3	25.1	17.9	17.5	18.1
		15	4.5	1048	832	731	26.1	26.1	24.3	16.7	18.8	18.7
		15	9	624	969	674	27.5	27.4	25.7	19.3	19.3	19.0
		15	18	961	653	596	25.9	31.9	27.7	16.5	17.3	16.8

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 35. Effects of preplant band and seed band rates of N and P and row area location on grain yield and grain composition of winter wheat (Marion Co., 1982).

Preplant band		Seed band		Row area*			Row area*			Row area*		
N	P	N	P	A	B	C	A	B	C	A	B	C
----kg/ha----		--kg/ha---		-Grain yield (g/m^2)-			-Grain protein (%)-			---Grain P (%)---		
70	0	0	0	360	258	387	14.3	14.3	14.3	0.31	0.29	0.33
		15	0	438	242	293	14.1	14.0	14.1	0.37	0.35	0.37
		15	4.5	437	385	387	14.1	14.2	14.2	0.29	0.33	0.33
		15	9	376	341	327	14.1	14.1	14.2	0.35	0.37	0.33
		15	18	318	371	290	13.8	13.6	13.5	0.33	0.30	0.29
70	9	0	0	508	381	218	14.5	14.4	14.1	0.35	0.33	0.33
		15	0	462	354	390	13.8	14.5	14.0	0.34	0.37	0.33
		15	4.5	629	311	288	14.1	13.8	13.7	0.33	0.32	0.33
		15	9	477	235	247	13.5	14.1	14.0	0.37	0.37	0.33
		15	18	379	348	337	13.4	13.0	14.1	0.29	0.29	0.35
70	18	0	0	411	324	360	14.2	14.0	14.0	0.35	0.30	0.30
		15	0	510	241	298	13.8	14.3	14.3	0.31	0.30	0.33
		15	4.5	457	407	325	14.0	13.7	13.8	0.33	0.31	0.33
		15	9	332	514	331	13.3	13.5	13.6	0.31	0.33	0.31
		15	18	403	354	276	13.6	13.5	13.5	0.31	0.31	0.32

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 36. Main effect of seed band rate of N and P on grain yield and grain yield components of winter wheat in sampled row areas (Marion Co., 1982).

Seed band N	Seed band P	Spikes/m^2	Kernels/ spike	Kernel wt. (mg)	Grain yield (g/m^2)
--kg/ha--					
0	0	706	25.9	19.6	357
15	0	746	26.5	18.2	359
15	4.5	830	26.2	18.7	403
15	9	777	25.7	17.7	354
15	18	749	26.6	17.4	342

The number of spikes/m^2 tended to increase when N alone or 4.5 kg P/ha with N were applied with the seed, compared to the control. The addition of higher rates of P (9 or 18 kg P/ha) tended to decrease the number of spikes/m^2 when compared to the rate of 4.5 kg P/ha. This was due to lodging of the wheat at the highest P rates. As shown in the results of the earlier plant sampling, the two highest rates of seed-banded P fertilizer produced significant increases in wheat growth, which resulted in taller plants, more susceptible to lodging (Lodging in this study was caused by very strong winds at the end of May). The plants that lodged remained so until harvest, and therefore could not realize their potential for spike production. The two highest rates of seed-banded P fertilizer not only tended to produce less spikes/m^2, but also tended to produce lower mean kernel weights than the treatment with 4.5 kg P/ha (Table 36). These effects combined seemed to have caused the reduction in grain yield at the two highest rates of P.

There was a significant preplant rate by row area interaction for the number of spikes/m^2 and grain yield. The addition of P to the preplant band tended to increase the number of spikes/m^2 and grain yield in row areas over preplant band, whereas it tended to decrease these variables in row areas midway between preplant bands (Table 37). These results are similar to those obtained in the study conducted in Dickinson Co. during 1981-82. Significant differences between row areas in number of spikes/m^2 and grain yield existed in the preplant rates with P, but not in the preplant rate without P.

Table 37. Effects of preplant band rate of N and P and row area location on grain yield and spike density of winter wheat, averaged over seed band rates (Marion Co., 1982).

Preplant band		Row area*		
N	P	A	B	C
------kg/ha------		----Grain yield (g/m^2)------		
70	0	386	320	337
70	9	491	326	296
70	18	423	368	318
		---------Spikes/m^2----------		
70	0	772	682	696
70	9	1076	690	646
70	18	884	716	690

L.S.D. 0.05	Grain yield	Spikes/m^2
between row areas within a preplant rate	.65	131
between preplant rates	N.S.	N.S.

* A = 11.5 cm of row centered over a preplant band.

B = 11.5 cm of row centered between A and C.

C = 11.5 cm of row centered between preplant bands.

Table 38. Effects of preplant band and seed band rates of N and P on grain yield and grain composition of winter wheat (Marion Co., 1982).

Preplant band N	Preplant band P	Seed band N	Seed band P	Grain Yield	Grain Protein	Grain P
----kg/ha----		--kg/ha--		---kg/ha---	------%------	---%---
70	0	0	0	3796	13.1	0.26
		15	0	3631	13.1	0.27
		15	4.5	3916	13.2	0.24
		15	9	3694	13.2	0.28
		15	18	3263	13.2	0.28
70	9	0	0	4017	13.3	0.25
		15	0	4100	13.0	0.25
		15	4.5	3726	13.1	0.27
		15	9	3282	12.9	0.29
		15	18	3105	13.1	0.29
70	18	0	0	3276	13.5	0.30
		15	0	3529	13.3	0.29
		15	4.5	3346	13.1	0.30
		15	9	2870	13.2	0.29
		15	18	2725	13.2	0.30
Mean Values:						
	Preplant band					
		70	0	3660	13.2	0.27
		70	9	3646	13.1	0.27
		70	18	3149	13.3	0.30
	Seed band					
		0	0	3696 a+	13.3	0.27
		15	0	3753 a	13.1	0.27
		15	4.5	3663 ab	13.1	0.27
		15	9	3282 bc	13.1	0.29
		15	18	3031 c	13.2	0.29

+ Means followed by the same letter within a column are not significantly different according to pairwise comparisons using Fisher's L.S. D. at the 0.05 level of probability.

The data for tiller survival are not presented because their high variability did not allow the determination of any significant pattern.

Grain harvest

The results obtained at harvest and the corresponding analyses of variance are presented in Table 38 and Appendix Table A-16, respectively. Grain yields were significantly affected by seed band rate but not by preplant rate. The application of N alone or N and 4.5 kg P/ha with the seed did not have any significant effect on grain yield compared to the control, but the application of N and 9 or 18 kg P/ha significantly decreased grain yields. According to the results of the spike sampling, these grain yield decreases were mainly due to decreases in the number of spikes/m^2 and mean kernel weight. Grain composition was not significantly affected by any of the factors.

The results of this study show that the increases in tillering and early dry matter production obtained with the use of seed-banded fertilizer can result in reduced grain yields if the increased wheat growth and unfavorable climatic conditions result in lodging of the plants.

Greenhouse Study

The results obtained in the greenhouse study are summarized in Tables 39 through 41; the analyses of variance of these results can be found in Appendix Tables A-19 through A-27.

At 10 days after planting, neither the location of the plant with respect to the preplant band, nor the seed band rate had produced significant effects on the dry matter weight of shoots (Table 39). However, both factors had significantly affected the total P content in shoots and the amount of P absorbed from the preplant band. Plants growing over a preplant band had a higher total P content than plants growing to the side of a preplant band (Table 40). Similarly, plants with seed-banded fertilizer had a higher total P content than plants without seed-banded fertilizer. Plants located over a preplant band had absorbed significantly more P from the preplant band when growing without seed-banded fertilizer than when growing with seed-banded fertilizer. Scanning of the plants with a properly shielded Geiger counter at emergence determined that, at that time, plants growing over preplant bands already contained P from the preplant band. Therefore, these plants started absorbing P from the preplant band between germination and emergence. Plants growing to the side of a preplant band had not absorbed P from the preplant band by the first sampling date.

At 20 days after planting, plants without seed-banded fertilizer had higher shoot dry matter when growing over a preplant band than when growing to the side of a preplant band (Table 39). This is probably the reason why the addition of seed-banded fertilizer produced larger dry matter increases in plants to the side of a preplant band than in plants over a preplant band. There were no significant differences in total P

Table 39. Effects of seed band rate of N and P, and row location on dry weight of winter wheat shoots, number of tillers per plant, and total N in shoots, at four sampling dates (Greenhouse study).

Time after planting	Seed band N	Seed band P	Row location* Over	Row location* Side	Row location* Over	Row location* Side	Row location* Over	Row location* Side
--days--	----kg/ha-----		---Wt./plant (mg)---		----Tillers/plant----		----Total N/plant (ug)----	
10	0	0	11.6	11.5	1.0	1.0	612	582
	15	4.5	12.7	11.9	1.0	1.0	709	638
20	0	0	51.6	33.3	1.1	1.0	2,843	1,567
	15	4.5	59.9	53.7	1.2	1.0	3,266	2,860
30	0	0	102.5	51.7	2.9	1.0	5,277	2,319
	15	4.5	125.7	98.5	2.9	2.6	6,629	4,889
40	0	0	174.9	79.3	4.7	2.1	9,037	3,908
	15	4.5	219.3	173.2	5.4	4.0	11,337	8,321

	L.S.D. 0.05	Wt./plant (mg)	Tillers/plant	Total N/plant (ug)
10 days	between row locations	N.S.	----	69
	between seed band rates	N.S.	----	72
20 days	between row locations	4.9	N.S.	330
	between seed band rates	5.5	N.S.	336
30 days	between row locations	35.3	0.3	1,988
	between seed band rates	34.6	0.4	1,735
40 days	between row locations	31.2	0.6	1,837
	between seed band rates	31.2	0.9	1,648

* Over = row located 10 cm directly over the preplant band.
Side = row located 10 cm over and 17 cm to the side of the preplant band.

Table 40. Effects of seed band rate of N and P, and row location on total P, and amount and proportion of P absorbed from the preplant band in winter wheat shoots, at four dates (Greenhouse study)

Time after planting	Seed band N	Seed band P	Row location* Over	Row location* Side	Row location* Over	Row location* Side	Row location* Over	Row location* Side
--days--	-----kg/ha-----		--Total P/plant (ug)--		--Preplant P/plant (ug)--		--Preplant P (%)**--	
10	0	0	55	46	8	0	15.0	0.0
	15	4.5	84	74	6	0	6.9	0.0
20	0	0	310	78	213	2	68.5	2.6
	15	4.5	350	260	85	1	23.9	0.4
30	0	0	608	143	521	24	85.5	14.0
	15	4.5	709	398	315	39	44.1	8.3
40	0	0	1041	303	861	98	82.7	29.7
	15	4.5	1280	567	791	83	61.4	13.9

	L.S.D. 0.05	Total P/plant (ug)	Preplant P/plant (ug)	Preplant P (%)
10 days	between row locations	7	2.0	2.1
	between seed band rates	8	1.6	1.5
20 days	between row locations	43	30.0	5.1
	between seed band rates	48	30.0	5.3
30 days	between row locations	213	166.0	14.6
	between seed band rates	181	150.0	11.0
40 days	between row locations	192	161.0	14.7
	between seed band rates	200	N.S.	14.9

* Over = row located 10 cm directly over the preplant band.
Side = row located 10 cm over and 17 cm to the side of the preplant band.

** Proportion of total P derived from the preplant band.

Table 41. Effect of row location on total P, and amount and proportion of P absorbed from the seed band in winter wheat shoots, at four sampling dates (Greenhouse study)

Time after planting	Row location*		L.S.D. 0.05
	Over	Side	
--days--	--Total P/plant(ug)--		
10	84	74	7
20	350	260	43
30	709	398	213
40	1280	567	192
	-Seed band P/plant(ug)-		
10	28	27	N.S.
20	155	159	N.S.
30	263	243	N.S.
40	257	308	N.S.
	---Seed band P (%)**---		
10	33.7	36.9	N.S.
20	44.5	61.0	6.6
30	37.5	62.3	14.2
40	22.1	54.6	9.9

* Over = row located 10 cm directly over the preplant band.

Side = row located 10 cm over and 17 cm to the side of the preplant band.

** Proportion of total P derived from the seed band.

content between plants located over preplant bands with and without seed-banded fertilizer (Table 40). However, as in the first sampling, there were differences between these plants in the amount of P absorbed from the preplant band. Plants over a preplant band absorbed about two and a half times more P from the preplant band when growing without seed-banded fertilizer than when growing with seed-banded fertilizer. The amount of P absorbed from the preplant band constituted 23.9 and 68.5% of the total P content in plants growing over a preplant band, with and without seed-banded fertilizer, respectively.

These results differ significantly from those obtained by Maxwell (1980). In his study, Maxwell found that plants growing over a preplant band (without seed-banded fertilizer) did not contain any P from the preplant band at 11 days after planting; at 22 days after planting, only 3% of the total P content came from the preplant band, compared to 68.5% (at 20 days) in the present study. The delay in P uptake from the preplant band in Maxwell's study could have been due to the fact that he used ammonium hydroxide as the N source for the preplant band. Research by Brage et al. (1960) has shown that considerable amounts of NH_3 can evolve from the soil atmosphere when ammonium hydroxide is mixed with the soil. The NH_3 evolved from a fertilizer band can prevent root extension into the band, and consequently, nutrient absorption from the band. In the same study by Brage et al., ammonium nitrate (the N source used in the present study) was found to release very small amounts of NH_3 when mixed with the soil.

At 20 days after planting, plants growing to the side of a preplant band had a higher total P content when growing with seed-banded fertilizer than when growing without seed-banded fertilizer (Table 40). By this sampling date, plants growing to the side of a preplant band had already started absorbing P from the preplant band. In this case, however, there were no significant differences in the amount of P absorbed from the preplant band between plants with and without seed-banded fertilizer.

The general effects observed at 30 and 40 days after planting were very similar to those discussed for the sampling conducted 20 days after planting. However, at 40 days after planting, there were no significant differences in the amount of P absorbed from the preplant band between plants placed over a preplant, with and without seed-banded fertilizer, respectively. Therefore, the delay in the uptake of P from the preplant band caused by the seed banded fertilizer did not last more than 40 days (Figure 5). The application of seed-banded fertilizer did not affect significantly the absorption of P from the preplant band, in plants growing to the side of a preplant band, at any of the sampling dates.

Since roots were not collected in this study, it is not possible to determine whether the delay in P uptake from the preplant band in plants growing over a preplant band was due to less root development toward the preplant band or to the lack of a large enough sink in the plant. However, assuming that this delay exists in the field, and that it is due to less root development toward the preplant band, the effect would probably not be very important

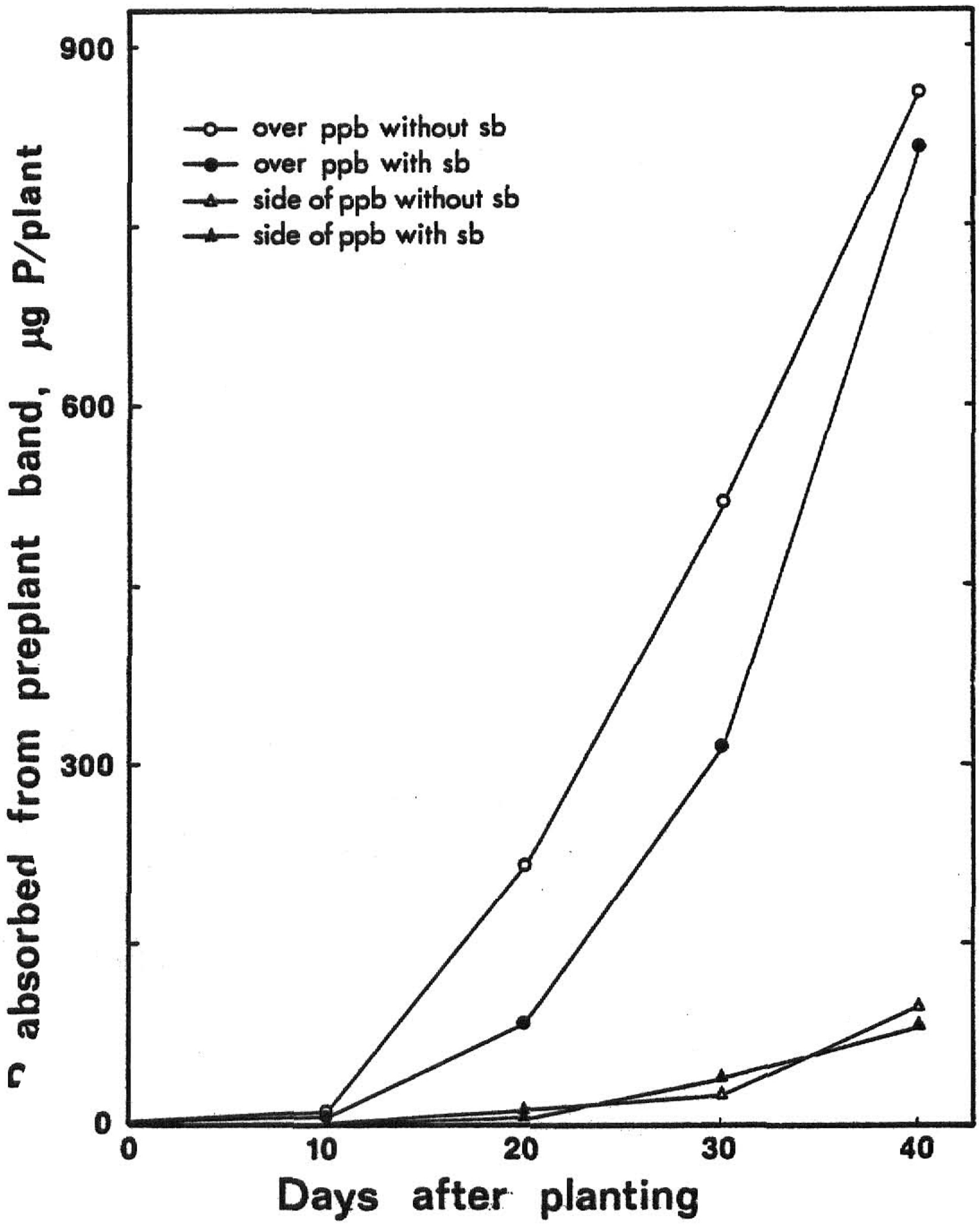


Fig. 5. Amount of P absorbed from the preplant band in plants growing either over or to the side of a preplant band, with and without seed-banded fertilizer. (SB = seed-banded fertilizer; PPB = preplant band).

since it seems to be of short duration. The lack of delay in the uptake of P from the preplant band in plants growing to the side of a preplant band seems to indicate that the seed-banded fertilizer did not affect the lateral growth of roots toward the prepland band.

There were no significant differences in the amount of P absorbed from the seed band between plants growing over and plants growing to the side of a preplant band, at any of the samplings (Table 41). Therefore, plant location with respect to the preplant band does not seem to affect the absorption of P from the seed-banded fertilizer (Figure 6).

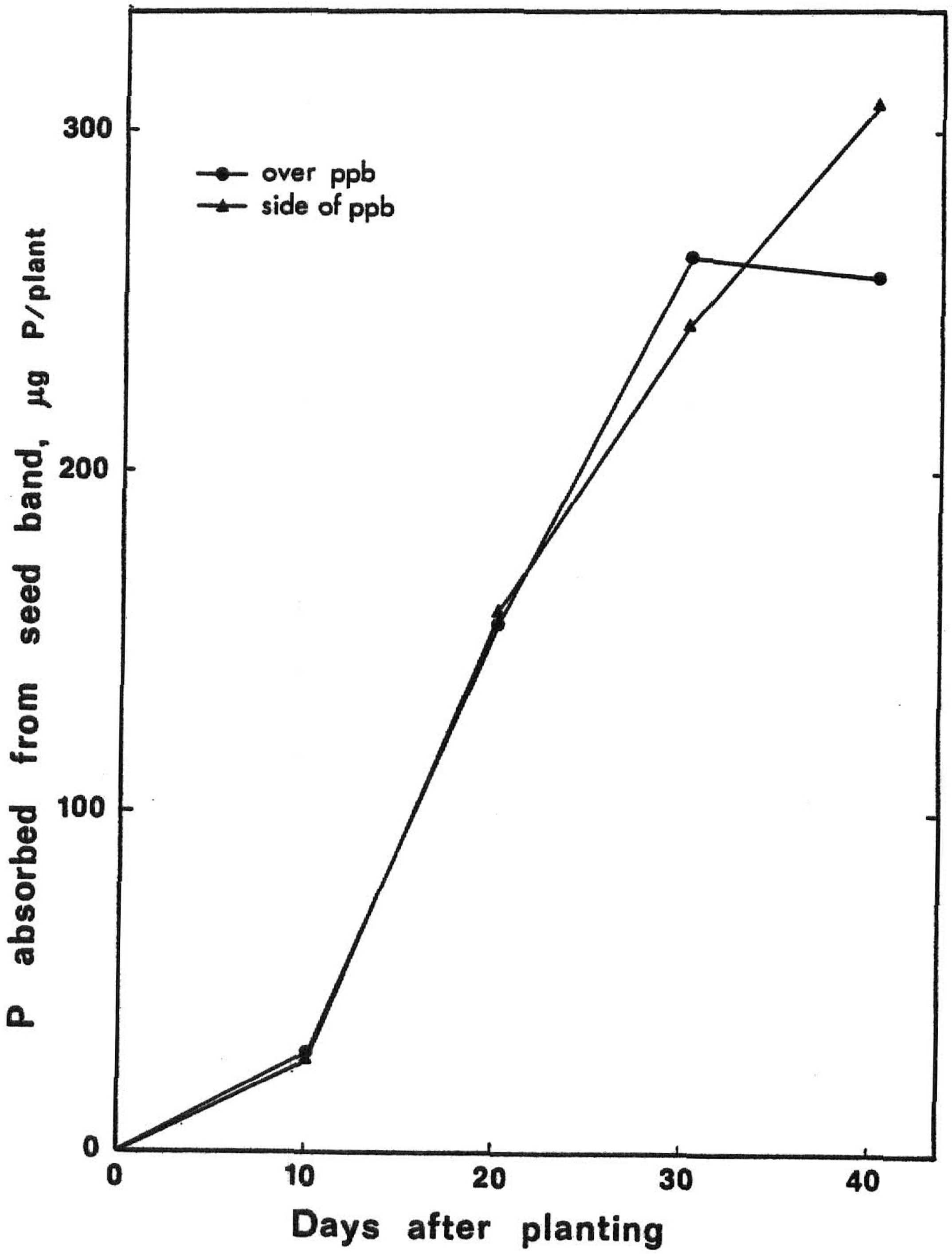


Fig. 6. Amount of P absorbed from the seed band in plants growing either over or to the side of a preplant band. (PPB = preplant band).

SUMMARY AND CONCLUSIONS

The results of the field studies show that when only N was applied in the preplant band, the "wavy effect" did not exist or was not as marked as when P was also added in the preplant band. The addition of P to the preplant band significantly increased tillering and early dry matter production in row areas over preplant bands, but either reduced or did not affect wheat growth in row areas midway between preplant bands. None of the studies showed a significant response to preplant-banded P for yields of dry matter and grain per hectare.

The application of N fertilizer with the seed did not affect wheat growth in any of the row areas. The application of N and P with the seed increased tillering and early dry matter production in all row areas, with larger increases usually obtained in row areas between preplant bands. These increases resulted in an overall increase in dry matter production.

The seed-banded N-P fertilizer enhanced wheat growth but failed to produce significant increases in grain yield in the 1981 study (Dickinson Co.), where the crop was exposed to water stress early in the spring, and in one of the 1982 studies (Marion Co.) where the enhanced growth caused lodging. In the latter case, the application of 15 kg N/ha with 9 or 18 kg P/ha significantly decreased grain yields. In the other 1982 study (Dickinson Co.), where soil moisture was not limiting and lodging did not occur, the application of seed banded fertilizer significantly increased grain yields by increasing spike density in row areas between preplant bands. Since this study showed no grain yield response to preplant-banded P, it was not possible to determine if the favorable effects of seed-banded fertilizer could be additive to the effects of preplant-banded P. More research would be needed to elucidate these aspects.

The results of the greenhouse study showed that the application of N and P fertilizer with the seed reduced the early absorption of P from the preplant band in plants growing over a preplant band, but did not affect it significantly in plants growing to the side of a preplant band. The effect observed in plants growing over preplant bands did not extend over 40 days. There were no significant differences in the amount of P absorbed from the seed band between plants growing over and plants growing to the side of a preplant band.

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APPENDIX

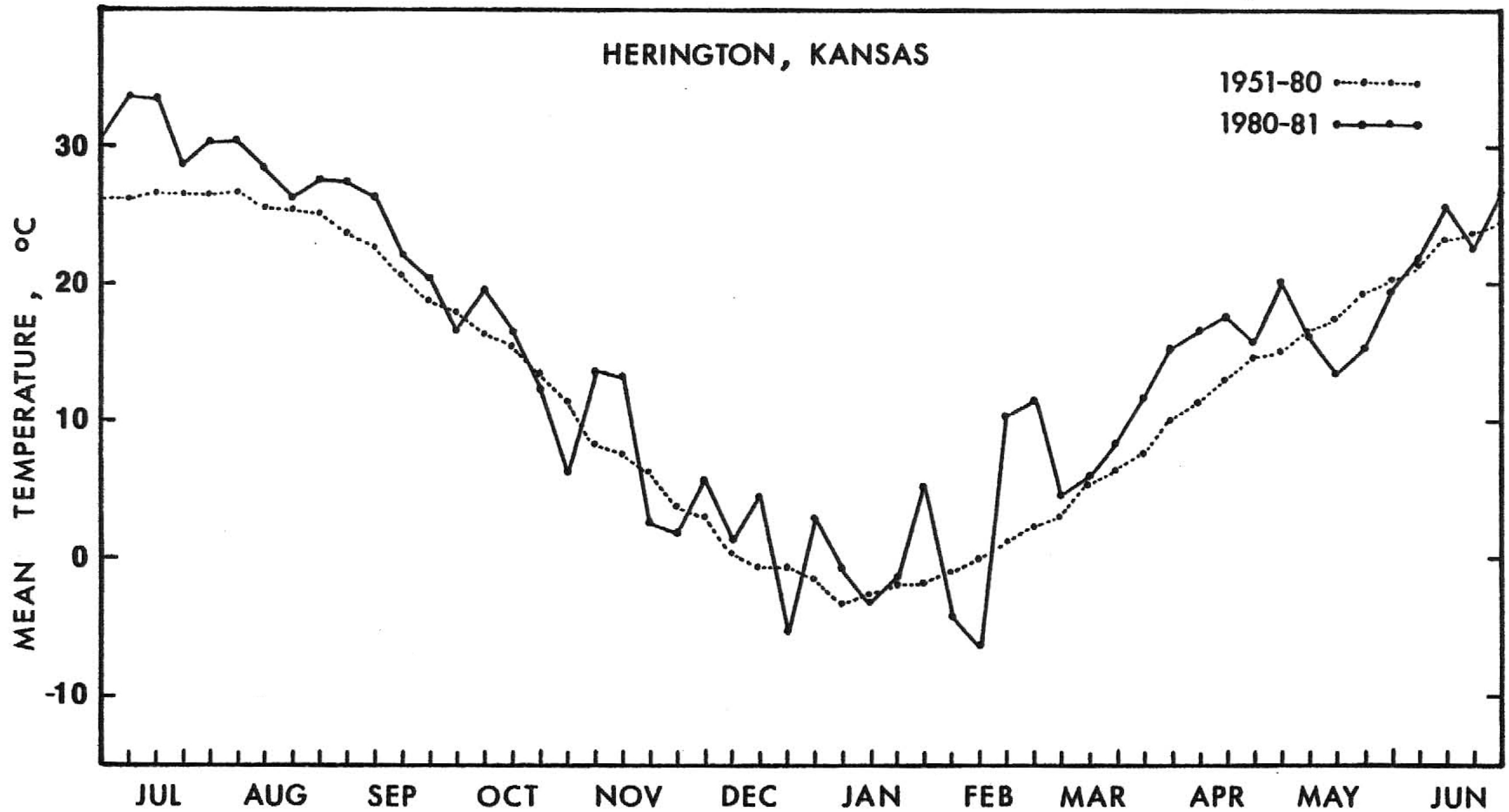

Fig. A-1. Long-term average (1951-80) of weekly mean temperatures, and weekly mean temperatures for 1980-81 at Herington, Kansas.

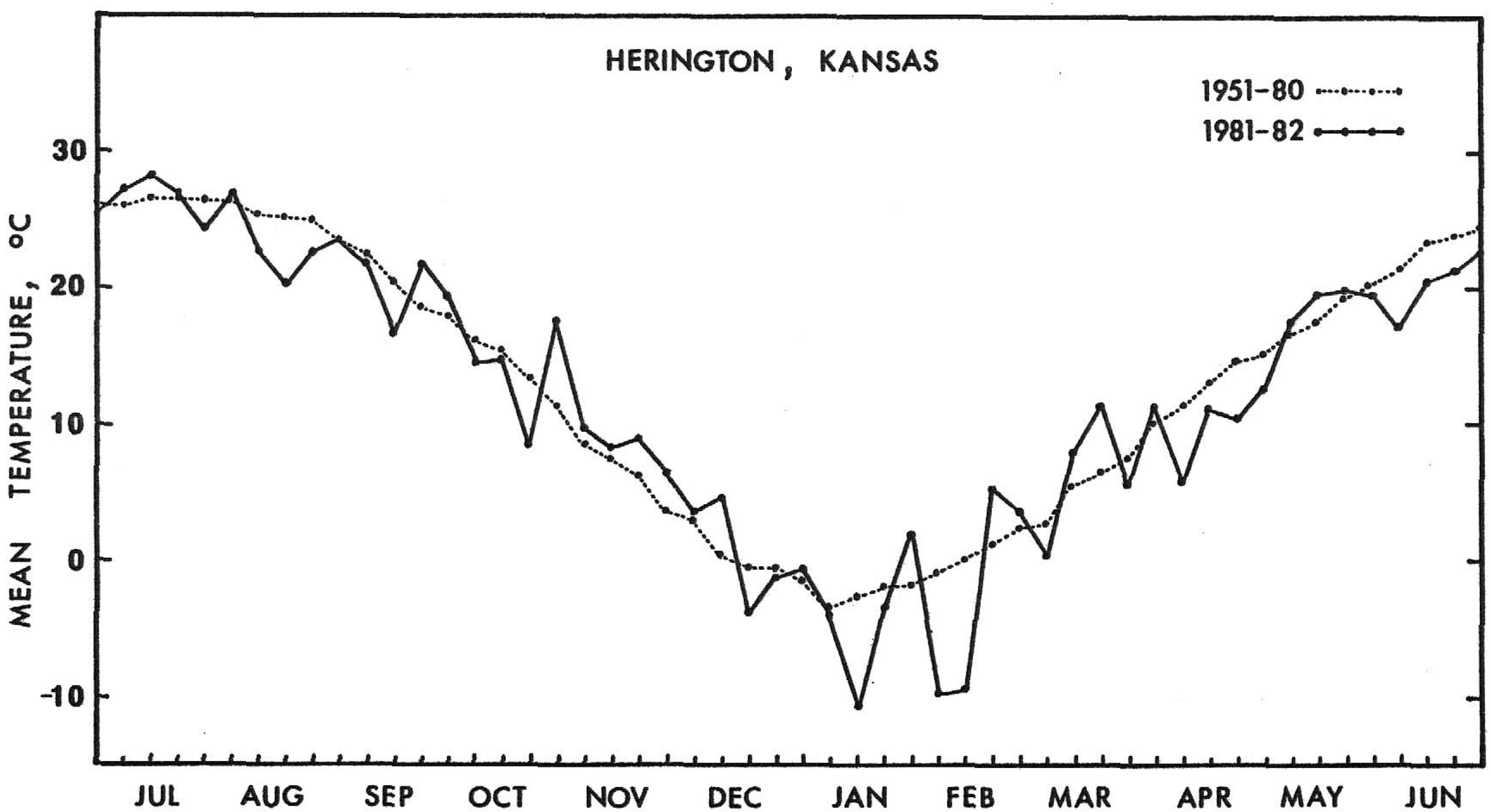

Fig. A-2. Long-term average (1951-80) of weekly mean temperatures, and weekly mean temperatures for 1981-82 at Herington, Kansas.

Fig. A-3. Long-term average (1951-80) of weekly cumulative precipitation, and weekly cumulative precipitation for 1980-81 and 1981-82 at Herington, Kansas.

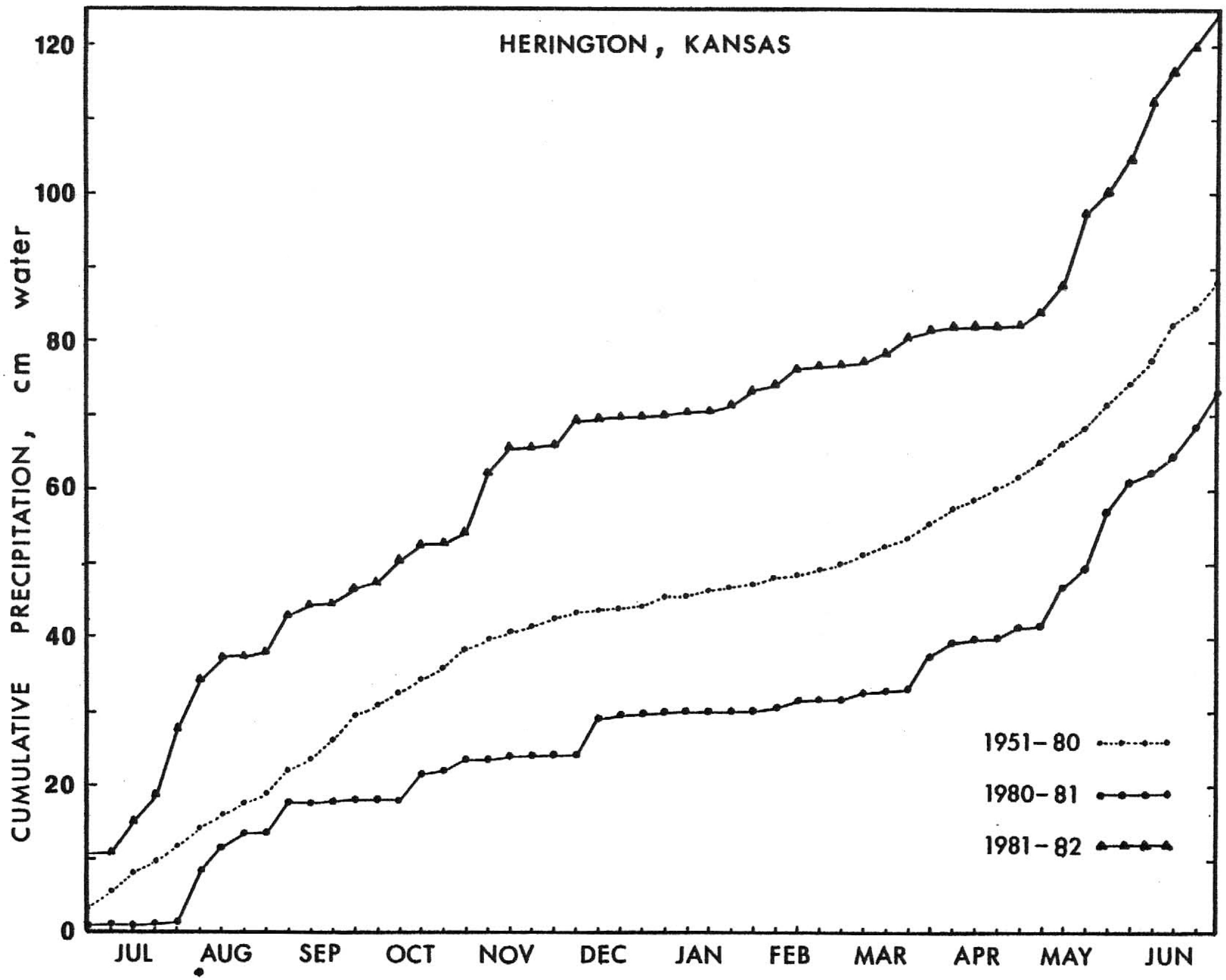
HERINGTON , KANSAS
CUMULATIVE PRECIPITATION, cm water
0
20
40
60
80
100
120
JUL
AUG
SEP
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
1951-80
1980-81
1981-82

Table A-1. Ten-day averages of air and soil temperatures and air relative humidity in the greenhouse study.

	Temperature				Air relative humidity	
	Soil(8 cm depth)		Air			
Days	8 a.m.	2 p.m.	8 a.m.	2 p.m.	8 a.m.	2 p.m.
	---------------°C---------------				----------%----------	
0-10	10.7	20.7	13.6	23.3	60.6	40.5
11-20	11.3	20.5	14.2	23.0	58.3	50.2
21-30	9.0	13.1	10.5	21.9	61.9	47.5
31-40	7.0	13.3	9.3	15.8	66.5	57.0
$\bar{x}$	9.5	16.9	11.9	21.0	61.8	48.8

Table A-2. Analysis of variance for tillers/m^2 at two counting dates (Dickinson Co.).

Source	DF	5 December 1980		28 February 1981	
		SS	F	SS	F
Seed band rate (SB)	4	254,052.2	9.58**	2,504,203.1	6.96**
Replication	3	104,659.6	5.26*	1,087,152.1	4.03*
Main plot error	12	79,538.9		1,079,283.1	
Row Area (RA)	2	153,327.2	6.50**	3,747,527.6	27.63**
SB x RA	8	54,054.9	0.57	304,475.3	0.56
Subplot error	30	353,929.8		2,034,475.9	
Total	59	999,562.6		10,757,116.9	

In this and following tables, * and ** indicate significance at the 0.05 and 0.01 level, respectively.

Table A-3. Analysis of variance for dry matter yield and tissue N and P concentrations from sampled row areas (Dickinson Co., 14 March 1981).

		Variable					
		Dry matter yield (g/m^2)		Tissue N (%)		Tissue P (%)	
Source	DF	SS	F	SS	F	SS	F
Preplant band rate (PPB)	2	7,778.2	2.92	1.012	3.38	0.0822315	6.88*
Replication	3	6,102.0	1.52	2.220	4.94*	0.0148585	0.83
Main plot error	6	7,999.9		0.898		0.0358121	
Seed band rate (SB)	4	33,171.5	12.61**	0.861	3.33*	0.03536752	7.79**
PPB x SB	8	7,715.2	1.47	0.383	0.74	0.0087220	0.96
Subplot error	36	23,672.0		2.326		0.0408779	
Row Area (RA)	2	431,107.9	459.25**	4.197	108.67**	0.2075408	401.80**
PPB x RA	4	3,092.0	1.65	0.146	1.89	0.0244341	23.65**
SB x RA	8	5,825.6	1.55	0.482	3.12**	0.0076777	3.72**
PPB x SB x RA	16	4,256.6	0.57	0.437	1.41	0.0059997	1.45
Sub-subplot error	90	42,253.7		1.738		0.0232437	
Total	179	572,974.6		14.700		0.4867655	

Table A-4. Analysis of variance for dry matter yield at two sampling dates (Dickinson Co., 1981).

Source	DF	14 March 1981		2 May 1981	
		SS	F	SS	F
Preplant rate (PPB)	2	313,387.9	3.48	834,484.8	0.18
Replication	3	148,688.1	1.10	2,200,845.0	0.32
Main plot error	6	270,096.0		13,602,147.1	
Seed band rate (SB)	4	1,109,293.4	13.08**	8,711,100.2	2.76*
PPB x SB	8	296,130.8	1.75	10,426,325.0	1.65
Subplot error	36	763,527.4		28,451,225.2	
Total	59	2,901,123.6		64,226,627.3	

Table A-5. Analysis of variance for dry matter yield and tissue N and P concentrations from sampled row areas (Dickinson Co., 2 May 1981).

Source	DF	Variable: Dry matter yield(g/m^2)		Tissue N (%)		Tissue P (%)	
		SS	F	SS	F	SS	F
Preplant band rate (PPB)	2	13,899.9	0.11	0.4222300	1.36	0.0225605	3.88
Replication	3	93,550.8	0.49	0.7256311	1.56	0.0033676	0.39
Main plot error	6	377,597.8		0.9320722		0.0174396	
Seed band rate (SB)	4	215,461.9	2.10	0.3415778	1.28	0.0095503	3.49*
PPB x SB	8	350,578.7	1.70	0.4624089	0.87	0.0048790	0.89
Subplot error	36	925,435.3		2.3977467		0.0245357	
Row Area (RA)	2	4,093,600.3	140.92**	0.0873433	2.83	0.0033237	13.27**
PPB x RA	4	494,230.5	8.51**	0.1502267	2.43	0.0008953	1.79
SB x RA	8	257,032.8	2.21*	0.1418622	1.15	0.0023682	2.36*
PPB x SB x RA	16	221,885.6	0.95	0.4168011	1.69	0.0009520	0.48
Sub-subplot error	90	1,307,246.1		1.3905000		0.0112702	
Total	179	8,350,519.7		7.4684000		0.1011421	

Table A-6. Analysis of variance for spikes/m^2, kernels/spike and mean kernel weight from sampled row areas (Dickinson Co., 1981).

Source	DF	Spikes/m^2 SS	Spikes/m^2 F	Kernels/spike SS	Kernels/spike F	Kernel wt (mg) SS	Kernel wt (mg) F
Seed band rate (SB)	4	67,028.9	0.96	51.3	2.38	1.37	0.05
Replication	3	435,304.8	8.29**	18.9	1.17	8.25	0.38
Main plot error	12	209,964.8		64.7		87.35	
Row Area (RA)	2	1,382,184.5	39.48**	32.0	2.97	10.34	1.80
SB x RA	8	74,454.2	0.53	81.6	1.89	24.88	1.08
Subplot error	30	525,113.9		161.7		86.14	
Total	59	2,694,051.1		410.2		218.33	

Table A-7. Analysis of variance for grain yield and grain protein and P concentrations from sampled row areas (Dickinson Co., 1981).

		Variable					
		Grain yield (g/m^2)		Grain protein (%)		Grain P (%)	
Source	DF	SS	F	SS	F	SS	F
Seed band rate (SB)	4	30,190.9	0.44	25.9	1.92	0.0053106	1.29
Replication	3	269,269.9	5.20*	34.7	3.43	0.0343402	11.1**
Main plot error	12	207,019.0		40.5		0.0123169	
Row Area (RA)	2	748,609.7	36.45**	1.2	1.60	0.0007789	0.52
SB x RA	8	65,167.8	0.79	3.1	1.05	0.0078549	1.30
Subplot error	30	308,046.7		11.1		0.0226082	
Total	59	1,628,304.0		116.5		0.0832097	

Table A-8. Analysis of variance for percent tiller survival (Dickinson Co., 1981).

Source	DF	Tiller survival (%)	
		SS	F
Seed band rate (SB)	4	1,104.80	4.80*
Replication	3	2,095.69	12.14**
Main plot error	12	690.19	
Row Area (RA)	2	970.07	13.05**
SB x RA	8	323.97	1.09
Subplot error	30	1,115.13	
Total	59	6,299.85	

Table A-9. Analysis of variance for grain yields and grain protein and P concentrations (Dickinson Co., 1981).

Source	DF	Grain yield (kg/ha)		Grain Protein (%)		Grain P (%)	
		SS	F	SS	F	SS	F
Preplant band rate (PPB)	2	134,084.3	0.21	0.69	0.15	0.0031899	0.39
Replication	3	933,275.1	0.99	16.97	2.44	0.0066041	0.53
Main plot error	6	1,885,905.1		13.88		0.0247482	
Seed band rate (SB)	4	377,614.5	0.97	2.79	1.02	0.0038086	2.11
PPB x SB	8	412,025.2	0.53	8.80	1.61	0.0011659	0.32
Subplot error	36	3,506,843.3		24.63		0.0162387	
Total	59	7,249,747.5		67.76		0.0562485	

Table A-10. Analysis of variance for dry matter yield, tillers/m^2, and tissue N and P concentrations from sampled row areas (Dickinson Co., 27 March 1982).

Source	DF	Dry matter yield(g/m^2)		Tillers/m^2		Tissue N (%)		Tissue P (%)	
		SS	F	SS	F	SS	F	SS	F
Preplant band rate (PPB)	2	4,927.4	2.45	2,465,744	5.46*	8.50	22.35**	0.3764581	46.55**
Replication	3	172.6	0.06	231,250	0.34	0.27	0.47	0.0072789	0.60
Main plot error	6	6,024.6		1,354,913		1.14		0.0242612	
Seed band rate (SB)	4	17,756.2	10.78**	6,241,684	14.58**	2.69	4.02**	0.0985577	11.17**
PPB x SB	8	2,278.1	0.69	1,117,569	1.31	2.54	1.90	0.0304275	1.72
Subplot error	36	14,827.2		3,853,572		6.02		0.0794075	
Row Area (RA)	2	39,220.0	96.09**	10,630,446	58.31**	4.64	58.36**	0.2214098	214.96**
PPB x RA	4	10,899.9	13.35**	3,074,899	8.43**	0.85	5.36**	0.0651820	31.64**
SB x RA	8	3,492.0	2.14*	2,121,063	2.91**	0.46	1.45	0.0117603	2.85**
PPB x SB x RA	16	6,591.0	2.02*	2,895,555	1.99**	1.15	1.81*	0.0140019	1.70
Sub-subplot error	90	18,367.9		8,204,105		3.58		0.0463512	
Total	179	124,556.9		42,190,800		31.84		0.9750961	

Table A-11. Analysis of variance for dry matter and grain yields, and grain protein and P concentrations (Dickinson Co., 1982).

Source	DF	Dry matter yield (kg/ha)		Grain yield (kg/ha)		Grain Protein(%)		Grain P (%)	
		SS	F	SS	F	SS	F	SS	F
Preplant band rate (PPB)	2	199,094.4	3.48	564,916.3	1.01	1.54	1.25	0.0007258	0.36
Replication	3	14,528.7	0.17	356,711.4	0.43	3.61	1.96	0.0074453	2.46
Main plot error	6	171,574.2		1,673,790.0		3.68		0.0060446	
Seed band rate (SB)	4	620,288.2	10.98**	1,596,636.9	3.78*	5.72	5.81**	0.0044947	0.70
PPB x SB	8	95,449.1	0.84	1,187,148.9	1.41	2.87	1.46	0.0344608	2.70*
Subplot error	36	508,466.3		3,798,715.4		8.87		0.0574296	
Total	59	1,609,400.9		9,177,918.9		26.29		0.1106008	

Table A-12. Analysis of variance for spikes/m^2, kernels/spike and mean kernel weight from sampled row areas (Dickinson Co., 1982).

Source	DF	Spikes/m^2 SS	Spikes/m^2 F	Kernels/spike SS	Kernels/spike F	Kernel wt (mg) SS	Kernel wt (mg) F
Preplant band rate (PPB)	2	269,213.6	6.67*	13.4	0.91	36.8	2.70
Replication	3	139,775.6	2.31	23.9	1.08	18.3	0.90
Main plot error	6	120,997.5		44.0		40.9	
Seed band rate (SB)	4	268,684.9	3.06*	61.6	1.84	52.0	4.85**
PPB x SB	8	228,871.9	1.30	59.4	0.89	50.3	2.35*
Subplot error	36	791,389.1		301.3		96.5	
Row Area (RA)	2	4,778,038.9	147.15**	17.0	3.05	14.8	3.00
PPB x RA	4	1,294,058.7	19.93**	25.5	2.29	1.5	0.15
SB x RA	8	281,807.9	2.17*	47.1	2.11*	47.7	2.41*
PPB x SB x RA	16	336,657.1	1.30	29.1	0.65	30.7	0.78
Sub-subplot error	90	1,461,162.9		250.6		222.6	
Total	179	9,970,658.1		872.9		612.1	

Table A-13. Analysis of variance for grain yield and grain protein and P concentrations from sampled row areas (Dickinson Co., 1982).

Source	DF	Grain Yield (g/m^2) SS	Grain Yield (g/m^2) F	Grain Protein(%) SS	Grain Protein(%) F	Grain P (%) SS	Grain P (%) F
Preplant band rate (PPB)	2	144,655.0	10.88*	7.087	2.84	0.0327211	11.12**
Replication	3	85,682.6	4.29	2.931	0.78	0.0052728	1.19
Main plot error	6	39,902.5		7.484		0.0088256	
Seed band rate (SB)	4	83,367.0	1.48	4.728	2.05	0.0136189	1.91
PPB x SB	8	105,493.7	0.94	3.150	0.68	0.0288844	2.03
Subplot error	36	507,532.3		20.743		0.0641767	
Row Area (RA)	2	2,089,192.8	156.77**	0.807	3.90*	0.0114878	3.58*
PPB x RA	4	609,205.7	22.86**	3.330	8.05**	0.0160256	2.50*
SB x RA	8	142,933.1	2.68*	1.240	1.50	0.0197178	1.54
PPB x SB x RA	16	126,131.8	1.18	1.279	0.77	0.0226689	0.88
Sub-subplot error	90	599,674.4		9.309		0.1445000	
Total	179	4,533,770.9		62.088		0.3678996	

Table A-14. Analysis of variance for percent tiller survival (Dickinson Co., 1982).

Source	DF	Tiller survival (%)	
		SS	F
Preplant band rate (PPB)	2	272.56	0.54
Replication	3	306.10	0.40
Main plot error	6	1,526.13	
Seed band rate (SB)	4	1,070.73	2.27
PPB x SB	8	1,349.69	1.43
Subplot error	36	4,248.48	
Row Area (RA)	2	2,061.01	10.51**
PPB x RA	4	1,550.76	3.96**
SB x RA	8	928.67	1.18
PPB x SB x RA	16	2,750.81	1.75
Sub-subplot error	90	8,821.95	
Total	179	24,886.89	

Table A-15. Analysis of variance for dry matter yield, tillers/m^2 and tissue N and P concentrations from sampled row areas (Marion Co., 3 April 1982).

Source	DF	Dry matter yield(g/m^2)		Tillers/m^2		Tissue N (%)		Tissue P (%)	
		SS	F	SS	F	SS	F	SS	F
Preplant band rate (PPB)	2	124,755.8	23.52**	3,804,364	14.86**	3.477	7.78*	0.3591663	17.35**
Replication	3	10,571.9	1.32	1,349,323	3.51	0.882		0.0138057	0.44
Main plot error	6	15,912.1		768,138		1.340		0.0621183	
Seed band rate (SB)	4	49,507.3	11.07**	2,089,631	3.79*	1.266	4.63*	0.1346599	25.37**
PPB x SB	8	17,476.1	1.95	1,030,088	0.93	0.318	0.58	0.0158405	1.49
Subplot error	36	40,231.3		4,965,681		2.459		0.0477781	
Row area (RA)	2	56,906.8	36.31**	4,077,716	22.32**	0.323	4.63*	0.0494279	52.23**
PPB x RA	4	26,927.3	8.59**	2,867,604	7.85**	0.090	0.65	0.0361984	19.12**
SB x RA	8	11,761.3	1.88	467,155	0.64	0.213	0.76	0.0071946	1.90
PPB x SB x RA	16	17,623.3	1.41	1,558,418	1.07	0.790	1.41	0.0090405	1.19
Sub-subplot error	90	70,520.2		8,221,098		3.141		0.0425867	
Total	179	442,193.4		31,199,216		14.299		0.7778169	

Table A-16. Analysis of variance for dry matter and grain yields, and grain protein and P concentrations (Marion Co., 1982).

		Variable							
		Dry matter (kg/ha)		Grain yield (kg/ha)		Grain Protein(%)		Grain P (%)	
Source	DF	SS	F	SS	F	SS	F	SS	F
Preplant band rate (PPB)	2	4,598,231.4	26.18**	3,385,802.7	1.50	0.4007	0.53	0.0104749	4.83
Replication	3	324,192.7	1.23	619,958.6	0.18	1.9760	1.76	0.0073633	2.26
Main plot error	6	526,864.0		6,754,171.2		2.2492		0.0065020	
Seed band rate (SB)	4	1,483,371.6	8.95**	4,744,698.2	5.27**	0.3236	0.68	0.0037507	1.99
PPB x SB	8	660,583.7	1.99	1,157,466.5	0.64	0.3330	0.35	0.0069783	1.85
Subplot error	36	1,491,559.5		8,101,828.5		4.3027		0.0169562	
Total	59	9,084,802.9		24,763,925.7		9.5852		0.0520254	

Table A-17. Analysis of variance for spikes/m^2, kernels/spike and mean kernel weight from sampled row areas (*Marion Co.*, 1982).

		Variable					
		Spikes/m^2		Kernels/spike		Kernel wt (mg)	
Source	DF	SS	F	SS	F	SS	F
Preplant band rate (PPB)	2	115,159.2	0.56	42.1	1.67	39.6	0.32
Replication	1	23,346.3	0.23	2.1	0.17	4.5	0.07
Main plot error	2	204,003.7		25.2		123.5	
Seed band rate (SB)	4	151,896.2	2.52	12.5	0.25	53.2	2.81
PPB x SB	8	158,125.9	1.31	49.3	0.49	43.7	1.15
Subplot error	12	181,135.7		150.7		56.7	
Row Area (RA)	2	1,009,893.6	24.61**	19.0	1.51	2.2	0.97
PPB x RA	4	380,022.0	4.63**	26.2	1.05	4.6	1.00
SB x RA	8	223,653.8	1.36	8.3	0.17	9.1	0.99
PPB x SB x RA	16	721,586.0	2.20*	97.1	0.97	16.6	0.90
Sub-subplot error	30	615,526.4		187.9		34.6	
Total	89	3,784,348.8		620.4		388.3	

Table A-18. Analysis of variance for grain yield, and grain protein and P concentrations from sampled row areas (Marion Co., 1982).

		Variable					
		Grain yield (g/m^2)		Grain Protein (%)		Grain P (%)	
Source	DF	SS	F	SS	F	SS	F
Preplant band rate (PPB)	2	10,481.5	0.56	0.916939	0.46	0.00474000	0.25
Replication	1	21,845.6	2.36	12.78030	12.76	0.0152100	1.62
Main plot error	2	18,552.5		2.003405		0.0188067	
Seed band rate (SB)	4	39,522.2	1.11	4.888806	6.22**	0.0137400	1.57
PPB x SB	8	31,805.7	0.45	1.031736	0.66	0.0087933	0.50
Subplot error	12	107,005.2		2.359638		0.0262000	
Row area (RA)	2	230,083.6	22.93**	0.041659	0.33	0.0001400	0.05
PPB x RA	4	68,890.4	3.43*	0.052559	0.21	0.0005000	0.09
SB x RA	8	76,774.9	1.91	1.217147	2.38*	0.0070600	0.65
PPB x SB x RA	16	182,222.1	2.27*	1.656051	1.62	0.0115667	0.54
Sub-subplot error	30	150,534.5		1.916910		0.0405333	
Total	89	937,718.2		28.865150		0.147290	

Table A-19. Analysis of variance for dry weights of shoots at four sampling dates (Greenhouse study).

Source	DF	10 days		20 days		30 days		40 days	
		SS	F	SS	F	SS	F	SS	F
Seed band rate (SB)	1	2.25	3.74	825.12	68.91**	4,917.51	12.76**	19,161.48	59.25**
Main plot error	6	3.61		71.84		2,313.09		1,940.35	
Row Location (RL)	1	0.81	1.23	596.58	73.35**	6,095.70	14.64**	20,071.81	61.67**
SB x RL	1	0.64	0.97	145.80	17.93**	555.78	1.33	2,452.73	7.54*
Subplot error	6	3.95		48.80		2,498.08		1,952.71	
Total	15	11.26		1688.14		16,380.16		45,579.08	

Table A-20. Analysis of variance for total N in shoots at four sampling dates (Greenhouse study).

Source	DF	10 days		20 days		30 days		40 days	
		SS	F	SS	F	SS	F	SS	F
Seed band rate (SB)	1	23,409.0	12.65*	2,946,372.3	75.36**	15,378,163	22.22**	45,081,153	65.52**
Main plot error	6	11,103.7		234,593.7		4,151,637		4,128,061	
Row Location (RL)	1	10,201.0	6.43*	2,825,761.0	77.73**	22,061,809	16.71**	66,336,953	58.90**
SB X RL	1	1,806.3	1.14	757,770.3	20.84**	1,483,524	1.12	4,463,713	3.96
Subplot error	6	9,511.7		218,133.7		7,923,474		6,757,811	
Total	15	56,031.7		6,982,631.0		50,998,607		126,770,000	

Table A-21. Analysis of variance for total P in shoots at four sampling dates (Greenhouse study).

Source	DF	10 days		20 days		30 days		40 days	
		SS	F	SS	F	SS	F	SS	F
Seed band rate (SB)	1	3,289.02	115.26**	49,328.4	52.44**	126,914.1	19.03**	253,764.1	17.67**
Main plot error	6	171.21		5,643.8		40,022.9		86,166.4	
Row Location (RL)	1	342.25	26.66**	104,006.3	174.69**	602,564.1	40.07**	2,106,126.6	172.53**
SB x RL	1	1.10	0.09	19,993.9	33.58**	23,485.6	1.56	637.6	0.05
Subplot error	6	77.01		3,572.2		90,228.9		73,244.4	
Total	15	3,880.59		182,544.6		883,215.6		2,519,939.1	

Table A-22. Analysis of variance for P absorbed from preplant band at three sampling dates (Greenhouse study).

Source	DF	20 days		30 days		40 days	
		SS	F	SS	F	SS	F
Seed band rate (SB)	1	16,679.7	54.81**	36,347.4	6.35*	7,310.3	0.64
Main plot error	6	1,825.8		34,368.1		68,290.5	
Row Location (RL)	1	86,641.9	299.00**	598,611.7	65.06**	2,162,370.3	250.90**
SB x RL	1	16,141.7	55.70**	48,885.2	5.31	3,080.8	0.36
Subplot error	6	1,738.7		55,209.6		51,710.5	
Total	15	123,027.8		773,422.0		2,292,761.9	

Table A-23. Analysis of variance for the proportion of P absorbed from the preplant band at two sampling dates (Greenhouse study).

Source	DF	20 days		40 days	
		SS	F	SS	F
Seed band rate (SB)	1	2,194.92	216.55**	1,374.56	18.15**
Main plot error	6	60.81		454.44	
Row Location (RL)	1	7,983.42	911.78**	10,105.27	139.25**
SB x RL	1	1,802.00	205.81**	30.53	0.42
Subplot error	6	52.53		435.40	
Total	15	12,093.68		12,400.20	

Table A-24. Analysis of variance for tillers/plant at two sampling dates (Greenhouse study).

Source	DF	30 days		40 days	
		SS	F	SS	F
Seed band rate (SB)	1	2.4806	45.97**	6.7600	17.43**
Main plot error	6	0.3237		2.3275	
Row Location (RL)	1	5.1756	195.61**	16.8100	168.80**
SB x RL	1	2.4806	93.76**	1.5625	15.69**
Subplot error	6	0.1587		0.5975	
Total	15	10.6192		28.0575	

Table A-25. Analysis of variance for P absorbed from seed band at four sampling dates (Greenhouse study).

Source	DF	10 days		20 days		30 days		40 days	
		SS	F	SS	F	SS	F	SS	F
Row Location	1	2.31	0.43	21.78	0.06	782.10	0.84	5,050.12	4.93
Replication	3	48.52	2.98	1,315.10	1.17	10,693.78	3.82	7,753.37	9.64
Error	3	16.26		1,127.31		2,801.46		1,572.37	
Total	7	67.09		2,464.19		14,277.34		14,375.86	

Table A-26. Analysis of variance for the proportion of P absorbed from the seed band at four sampling dates (Greenhouse study).

Source	DF	10 days		20 days		30 days		40 days	
		SS	F	SS	F	SS	F	SS	F
Row location	1	19.84	1.89	544.50	62.71**	1,237.53	30.94**	2,122.26	109.37**
Replication	3	60.85	1.93	48.43	1.86	201.81	1.68	42.12	0.72
Error	3	31.49		26.05		120.00		58.21	
Total	7	112.19		618.98		1,559.34		2,222.59	

Table A-27. Analysis of variance for variables with significant effects of rows and columns (Greenhouse study).

Source	DF	Tillers/plant 20 days		Preplant band P(ug P/plant) 10 days		P from preplant band (% of Total P) 10 days		P from preplant band (% of Total P) 30 days	
		SS	F	SS	F	SS	F	SS	F
Seed band rate (SB)	1	0.015625	25.06*	6.37	36.30*	66.830	2889.97**	2220.76	551.31**
Row	3	0.106875	57.00*	6.46	12.26	7.252	104.53**	326.01	26.98*
Column	1	0.015625	25.00*	0.95	5.41	1.381	59.70*	239.47	59.45*
Main plot error	2	0.001250		0.35		0.046		8.06	
Row Location (RL)	1	0.0756250	3.67	199.51	154.19**	478.520	330.82**	11529.39	161.51**
SB x RL	1	0.0156250	0.76	6.37	4.93	66.830	46.20**	1272.71	17.83**
Subplot error	6	0.1237500		7.76		8.680		428.32	
Total	15	0.354375		227.77		629.539		16024.72	

VITA

The author was born July 15, 1953 at Fray Bentos, Uruguay. He attended high school in Fray Bentos and graduated in 1970. He then entered Universidad de la Republica in Montevideo, where he obtained the degree of Ingeniero Agronomo in 1978. After graduation he worked for one year on his family's farm. In 1979 he came to the United States under an exchange program of the University of Minnesota. After receiving practical training at a crop farm in North Dakota and at an experiment station in Minnesota, he came to Kansas State University to work on a Master of Science degree in Agronomy.

EFFECTS OF SEED-BANDED AND PREPLANT-BANDED APPLICATIONS OF N AND P FERTILIZER ON WINTER WHEAT (*TRITICUM AESTIVUM* L.)

by

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ABSTRACT

The application of N and P fertilizer in widely spaced preplant bands (>25 cm) produces uneven growth of winter wheat ("wavy effect") in soils with low levels of available P. Plants growing directly over preplant bands show more vegetative growth and produce higher grain yields than plants growing between preplant bands. One field study was conducted in 1981 and two in 1982, to determine if the addition of fertilizer banded with the seed could increase the growth and final grain yield of plants growing between preplant bands, which in turn could result in an overall increase in grain yield. These studies evaluated the effects of combinations of seed-banded and preplant-banded N and P fertilizer on tillering, early dry matter production, grain yield and grain yield components of winter wheat, in sections of row located at difference distances from the preplant band. The wheat rows were drilled perpendicularly to the preplant bands.

When only N was applied in the preplant band, the "wavy effect" did not exist or was not as marked as when P was also added in the preplant band. The addition of P to the preplant band significantly increased tillering and early dry matter production in row sections over preplant bands, but either reduced or did not affect wheat growth in row sections between preplant bands. None of the studies showed a significant response to preplant-banded P for yields of dry matter and grain per hectare.

The application of N fertilizer with the seed did not affect wheat growth in any of the row sections. The application of N and P with the seed increased tillering and early dry matter production

in all row sections, with larger increases usually obtained in row sections between preplant bands. These increases resulted in an overall increase in early dry matter production.

The seed-banded N-P fertilizer enhanced wheat growth but failed to produce significant increases in grain yield in the 1981 study, where the crop was exposed to water stress early in the spring, and in one of the 1982 studies, where the enhanced growth caused lodging. In the latter case, the application of 15 kg N/ha with 9 or 18 kg P/ha significantly decreased grain yields. In the other 1982 study, where soil moisture was not limiting and lodging did not occur, the application of seed-banded fertilizer significantly increased grain yields by increasing spike density in row sections between preplant bands. Since this study showed no grain yield response to preplant-banded P, it was not possible to determine if the favorable effects of seed-banded fertilizer could be additive to the effects of preplant-banded P.

A study conducted in the greenhouse showed that the application of N and P fertilizer with the seed reduced the early absorption of P from the preplant band in plants growing over preplant bands without affecting it in plants growing to the side of a preplant band. This effect had disappeared by a sampling conducted 40 days after planting. There were no significant differences in the amount of P absorbed from the seed-banded fertilizer between plants growing over and plants growing to the side of a preplant band.