EFFECT OF PLACEMENT OF PHOSPHORUS
ON WINTER WHEAT

By

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Bachelor of Science in Agriculture

Oklahoma State University

Stillwater, Oklahoma

1979

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
December, 1981

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ACKNOWLEDGMENTS

I would like to express my appreciation to the Agronomy Department at Oklahoma State University for the facilities and equipment used in this study.

Furthermore, I am especially thankful to my major adviser, Dr. Robert Westerman, for his valuable guidance and support throughout the course of this study. To Drs. Billy Tucker and Charles Denman, I express gratitude for serving on my committee.

I would especially like to thank Randy Boman, for his tremendous help in the field and in the laboratory and his valued friendship as a fellow graduate student.

I would also like to express appreciation to my other fellow graduate students, Jim Stein, Bill Raun, Jeff Silvertooth, Monte Edlund, Larry Unrüh, Steve Moore, Sue Talley, and Greg Fox, who worked so diligently with me in performing the field work that made this study possible.

I would like to thank the cooperators whose farms were used in this study. At the Orienta location thanks to Mr. Ron Voth and at Snyder to Mr. Bob and Ralph Treadwell. Thanks to Jerry Walker, superintendant of the Research Station at Haskell.

Finally, I express deep appreciation to my family, Bob, Betty, Patricia, and my uncles Bill and Ralph Treadwell, for their help and support in my effort to accomplish this undertaking.

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CHAPTER I

INTRODUCTION

If a grower is going to stay in the farming industry he must increase his efficiency of crop production. Because fertilizers have become significant cost items in crop production, methods to improve fertilizer efficiency must be a high priority item in agricultural research. This study was devoted to finding the best and most economical way of placing phosphorus fertilizers to optimize utilization.

This study compares dual injection, banding, and broadcasting phosphorus in various methods of placement. Dual injection is the simultaneous injection of anhydrous ammonia and liquid ammonia polyphosphate through adjacent tubes behind an application knife, thereby banding the two materials in direct contact with one another.

Banding phosphate with the seed is the simultaneous placing of dry or liquid phosphorus material, such as diammonium phosphate or ammonium polyphosate, through adjacent tubes on the seed drill, the front one putting out seed and the back one putting down the fertilizer material.

The conventional method of putting down dry or liquid meaterials is by broadcasting. Broadcasting is the dropping or spraying, of a dry material or liquid material on the surface of the soil and then incorporating it into the soil prior to seeding.

Agronomist have long observed the beneficial effect of placing nitrogen and phosphorus in direct contact with each other in a band placement scheme, yet this method has not been widely used. Some growers are using dual injection in their operation because anhydrous ammonia is the cheapest nitrogen source and high analysis and ammonium polyphosate is fairly cheap and easy to apply. Growers using the broadcasting method might benefit from banding their phosphorus especially if they have a soil with a low phosphorus index or they have a soil with a high phosphorus fixing capacity. Time and labor could also be saved which would further increase their benefits. Banding smaller amounts of fertilizer with the seed as compared to broadcasting larger amounts to get the same crop yield would reduce the amount of fertilizer used and save a trip over the field.

These three methods were compared in this study on four separate soils in order to evaluate their relative effectiveness which would give growers better information to base fertilizer placement decisions.

CHAPTER II

REVIEW OF LITERATURE

Effect of Nitrogen on Phosphorus Uptake

Researchers have substantiated the fact that the ammonium form of nitrogen increases plant absorption of soil and fertilizer phosphorus. Robertson et al. (1954) found that phosphorus applied in a starter fertilizer slightly increased early vegetative growth when used alone; in combination with nitrogen in a band the increases for phosphorus were statistically significant. The final grain yields were increased significantly by fifteen bushels of corn. Robertson and his co-workers attributed this increase in phosphorus uptake to nitrogen, especially ammonium.

Smith et al. (1950) performed a study on oat forage using nitrogen and phosphorus. Applications of N or P gave highly significant increases in the percentage fertilizer P and decreases in the soil P taken up by the oats. The maximum increase or decrease was obtained when the highest rate of both N and P were applied together.

Lorenz and Johnson (1953) in a study using tomatoes, which showed that fertilized plants at low phosphate fertilization rates yielded more than double the fresh weight of those fertilized with nitrate at the same rate. Plants fertilized with nitrate and at very low (5 ppm) P showed severe phosphate deficiency symptoms.

Olsen and Dreier (1956a) reported that phosphorus placement with the seed of small grains is desirable in drier regions as long as the N put down with it does not exceed 15 pounds per acre. They pointed out that N is essential to maximize P fertilizer utilization, but large amounts of N and P applied should be separate from the seed.

Olsen and Dreier (1956b) found that fertilizer N stimulates plant use of fertilizer P through a wide range of soil conditions. The NH_4^+ ion apparently exceeds NO_3^- in this capacity, especially during early plant growth. With a low rate of P application, the N effect may be doubled the rate of fertilizer P use by the plant with soil P use changing very little.

pH Effects

The addition of ammoniacal N to the soil will cause a brief lowering of the pH due to hydrogen ions being generated through nitrification.

$$2NH_4^+ + 3O_2 \xrightarrow[\text{bacteria}]{\text{nitrosomonas}} 2NO_2^- + 2H_2O + 4H^+$$

$$2NO_2^- + O_2 \xrightarrow[\text{bacteria}]{\text{nitrobacter}} 2NO_3^-$$

Oxidation also occurs as follows (Grunes, 1959):

$$NH_4NO_3 + 2O_2 \qquad 2HNO_3 + H_2O$$

$$(NH_4)_2SO_4 + 4O_2 \qquad H_2SO_4 + 2HNO_3 + 2H_2O$$

For an equivalent amount of nitrogen, the ammonium sulfate would have a greater acidifying effect than ammonium nitrate. Preferential absorption by the plants of the rapidly absorbable ammonium ions over the slowly absorbable sulfate ions would also tend to decrease the pH. Hagen and Hopkins (1955) found H_2PO_4 in excised barley roots was absorbed through one site and HPO_4 through another site. The hydroxyl ion competitively inhibits absorption of both $H_2PO_4^-$ and $HPO_4^=$. They also found that the excised barley roots generally absorbed more P at pH 5.0 than at high pH levels.

Chapman (1935) states that previous work has shown that large applications of calcium nitrate slightly depressed plant growth on certain phosphate deficient soils, probably resulting from decreased solubility of the phosphate. The greatest result in growth besides the phosphate application, was produced by nitric acid. Ammonium sulfate, ammonium nitrate, and urea produced increases over calcium nitrate on two high phosphate soils, but did not increase yield for the low phosphate soil. General results indicate that physiologically acid nitrogen fertilizers are capable of increasing the phosphate availability on calcareous soils. Grunes et al. (1958a) unlike Chapman were working with added P in a study to determine the effect of placement and source of nitrogen on the availability of fertilizer and soil phosphorus to plants. The addition of nitrogen fertilizer generally increased the total percent phosphorus absorbed by plants from concentrated superphosphate bands. The addition of ammonium sulfate with the phosphorus band was more effective in increasing the percent of the total plant phosphorus from the fertilizer than was separate bands of nitrogen and phosphorus. Results show that the effect of nitrogen, on increasing the relative uptake of banded fertilizer phosphorus, was linked in increased top and root growth, and also with a decrease in soil pH.

Mamaril and Miller (1970) wanted to see if portions of soil which were treated with rubidium chloride as well as radioactive P labelled phosphate if the absorption of cations to the soil would be increased by NH_4^+ as causes increased absorption of cations to the soil. The NH_4^+ increased with increasing concentrations of NH_4^+. The absorption of $SO_4^=$ and Rb^+ were not affected by the presence of NH_4^+ to the same degree as was absorption fo P.

Caldwell (1960) using radioactive P labelled materials, studied the effect of nitrogen on the absorption of phosphorus by corn. Salts such as ammonium nitrate, ammonium sulfate, and ammonium chloride were found to really increase phosphorus absorption from superphosphate, but only when nitrogen and phosphorus were mixed together. Nitrogen in monammonium phosphate and ammoniated superphosphates increased the absorption of phosphorus. Salts such as calcium nitrate and ammonium nitrate mixed with superphosphate did not increase absorption of phosphorus.

Bouldin and Sample (1959) conducted studies in the greenhouse with monocalcium phosphate monohydrate, monoammonium phosphate, and diammonium phosphate to show that movement of P in the soil was not affected by the presence of ammonium or calcium. Pellets were made and placed on the surface of two soils, after a period of 5 weeks the distribution of soil-fertilizer P reaction products were measured with soil samples taken at various distances from the center of the pellet. Movement of P in the two soils were significantly affected, but differences among sources of P in the same soil were small.

Miller et al. (1970) stated that the addition of NH_4^+ ions to a P fertilizer band is known to increase the absorption of P. Pellets of radioactive P labelled monocalcium phosphate (MCP), MCP + K_2SO_4 or

MCP + $(NH_4)_2SO_4$ were placed in the soil to the side of a corn root tip growing in a glass box. Pictures of the area surrounding the pellets indicated an accumulation of P on the surface of roots in the MCP treatments but not the MCP + $(NH_4)_2SO_4$. Scans of root cross sections indicated a precipitation of P and Ca at the soil-root interface in the MCP and MCP + K_2SO_4 treatments. The pH of the interface was six tenths units lower in the MCP + $(NH_4)_2SO_4$ than in the MCP treatments. The higher ratio of $H_2PO_4^-/HPO_4^=$ ions at the lower pH is thought to be responsible for the prevention of the precipitation and the increased plant absorption uptake P in the presence of $(NH_4)_2SO_4$.

Riley and Barber (1971) conducted a study on soybeans using four soils with different initial soil pH values in a growth chamber. They limed the soil to induced pH changes. Ammonium fertilized soybeans absorbed more P and had a higher P concentration than NO_3 fertilized soybeans. The results of the soybeans grown with NH_4^+ and NO_3^- treatment at the four different pH levels showed that the P content of the shoots and roots were closely related to the pH of the soil surrounding the plant and not the pH of the bulk of the soil. They suggested that the increased availability of P where NH_4^+ was used was mainly due to the effect of the nitrogen source on the pH of the soil in close contact with the plant.

Blair et al. (1971) did a study to see if the reduction of the pH at the soil-root interface when NH_4^+ ions were absorbed is the cause of the increased P absorption in the presence of NH_4^+. Application of monocalcium phosphate with $(NH_4)_2SO_4$ was found to increase fertilizer P uptake when compared to MCP alone on soils with a high pH. No differences were measured on low pH soils. Phosphorus fertilizer uptake at 10 days was greatest where NH_4^+ and least where NO_3^- accompanied P. Changes in the pH at the soil-root interface and changes in the $H_2PO_4^-/HPO_4^=$ ratio at the root surface which were modified by the soil pH suggested, that NH_4^+ causes an increase in the uptake of P.

Physiological Effects of NH_4^+ on the Root

Willis and Yemm (1955) reported that the respiratory activity of detached barley roots increased when the roots were treated with nitrate salts and ammonium. This increase was in addition to the salt respiration commonly observed in placing high sugar-low salt roots in a salt solution. The increase in respiration occurred more quickly with ammonium than nitrate salts.

Miller (1965) found that the addition of $(NH_4)_2SO_4$ to a P band increased the absorption of fertilizer P by a single corn root. The development of lateral roots on the single root was increased by $(NH_4)_2SO_4$. He claims that the increased root growth was not a precondition for the increased absorption, and that $(NH_4)_2SO_4$ had some specific physiological effect on the absorption of P.

Thien and McFee (1970) studied the effect that metabolized N and N in solution had on P absorption and translocation in corn in the growth chamber. Corn plants of various N and P contents were pretreated in NH_4NO_3, P or water solutions for 24 hours. Plants were then transferred to treatment solution containing labelled P alone or with a N source. Nitrogen pretreatment of corn plants increased P absorption and translocation rates during the next 6 hours. These effects were absent when N was omitted from the pretreatment solution and accompanied P only during the treatment period indicating no companion effect of these two nutrients on movement into the root cells. The authors suggest the existence of a N requiring metabolite influencing the efficiency of P absorption and translocation in corn.

Leonce and Miller (1966) reported on the mechanism responsible for the increased P absorption which occurs when N is added to a P fertilizer band. Using radioactive P, they made a pellet containing P and either ammonium sulfate, ammonium chloride, or potassium nitrate in order to get N and radioactive P into a fertilizer as one. The addition of $(NH_4)_2SO_4$ or NH_4C to a pellet of radioactive P, concentrated superphosphate, placed to the side of a corn root greatly increased the labelled P content in the plant tops. The addition of KNO_3 reduced the P content of the tops when compared to concentrated superphosphate only. Pellets of fertilizer which consisted of phosphate only or phosphate plus potassium nitrate were combined with radioactive P, the labelled P accumulated to high levels in the root as revealed be autoradiographs. No such accumulation occurred in the presence of NH_4^+ ions. This indicated that the NH_4^+ ion must enter the root at the same point as P to cause increased P absorption. Therefore the NH_4^+ ion has a specific influence on the transfer of P.

Nutrient Uptake

Grunes and Krantz (1958) studied the increase of nitrogen, phosphorus and potassium in oats using corn or cotton in rotation with oats. Top-dressing with N before oats were plowed under in the "boot" stage increased N, P, and K concentrations by fifty percent in the forage for a four year period. The N top dressings increased the percentage of P in the tissue more than additions of K and P, but higher P concentrations were obtained with additions of NPK than with N alone. The effect of N on increasing the P and K concentrations in plant tops can also be related to an increase in root growth.

Bennett et al. (1953) set up a study to determine the effectiveness of side-dressed nitrogen on corn as shown by yield response and the composition of the corn leaf and grain. A great response to nitrogen occurred. The application of nitrogen increased the percent nitrogen in the leaf on all the experiments. Nitrogen content of the grain was increased in only 5 of the 8 experiments. Phosphorus percentage in the leaf was significantly increased due to nitrogen application. These increases were associated with yield responses which prove to be independent of the nitrogen effect. Power et al. (1961) states that fertilization with P, high soil moisture supplies at seeding time, and additional precipitation during the growing season, all increased total P uptake by spring wheat at all stages of plant growth. Although, P fertilization reduced soil P uptake. Moisture supplies at seeding and growing-season precipitation did not affect uptake of fertilizer P, except at tillering stage. Total P content of the plant material was not consistently altered by moisture or P fertilizer treatments and generally tended to decrease as plants approached maturity.

Carlson and Grunes (1958) studied the effect of fertilization on yield and nutrient content of barley by soil horizons. Nitrogen fertilizer increased barley yields on all horizons but phosphorus did not. When N and P were added together, yields were higher than when either was added alone. The yields on the surface horizon were highest at all fertilizer treatments.

Placement of Phosphorus

Tisdale and Nelson (1975) reported that the finer the soil texture, the greater the retention of added fertilizer phosphorus. If a finely divided soluble fertilizer phosphate is added to a soil by applying it broadcast and then disking it in, the phosphate is exposed to a greater amount of surface area; more fixation takes place than if the same amount of fertilizer had been applied in bands. Band placement reduces the surface contact between the soil and fertilizer with a consequent reduction in the amount of fixation. Although this is not the only factor to consider in the placement of a phosphorus fertilizer, it is one of considerable importance when a crop is to be grown on a low phosphate soil with a high fixing capacity and when maximum return from the money spent on phosphorus is desired. Band placement generally increases the plant utilization of the water-soluble phosphates such as the superphosphates, but there are other phosphatic fertilizers, which are classed as water-insoluble, whose plant utilization seems to be greater when mixed with the soil rather than when applied in bands.

Werkhoven and Miller (1960) conducted a greenhouse study to determine the effects of placement of phosphorus and nitrogen on absorption of fertilizer phosphorus by sugar beets. Seven placements of radioactive concentrated superphosphate combined with three nitrogen treatments were used. Placement of nitrogen had a greater influence on the uptake of fertilizer P than did placement of P. Nitrogen applied with the phosphorus generally resulted in greater uptake of fertilizer phosphorus than did nitrogen mixed with the soil. Nitrogen was more effective, when the P was banded than when it was mixed with a volume of soil 5.08 cm deep. When no nitrogen was added or when nitrogen was mixed with the soil, a shallow band placement or the applications mixed with 5.08 cm of soil were just as effective in supplying P to the plant, and were superior to either a deep band or a mixed application with a starter fertilizer.

Lawton et al. (1956) conducted both greenhouse and field studies with ammonium phosphate, dicalcium phosphate, ammonium nitrate, and potassium chloride prepared as slurries and then tried to evaluate the placement of these fertilizers on the nutrient value of the phosphorus in these mixed fertilizers. When either granular or pulverant fertilizer was banded in soil, the percentage of fertilizer phosphorus in water-soluble form was important in controlling the uptake of fertilizer phosphorus by crops. Both greenhouse and field studies showed a positive relationship between yield production or dry matter and the degree to which fertilizer phosphorus was soluble in water. They suggest that for maximum crop production, fertilizers applied in rows or bands should contain not less than 50 percent of their phosphorus in water-soluble form.

Terman et al. (1961) reported in a study with corn to phosphates varying in water solubility of phosphorus, as affected by rate, placement and seasonal environment that banding resulted in a greater response than mixing of the phosphates just prior to planting, this held true for the first crop and these were less dominate for the second and third crops.

Lutz et al. (1961) in a rate and placement study for small grains found that broadcasting and disking in, 10-9-9 a high water soluble fertilizer and 7-6-6 a low water soluble fertilizer, to supply 44.8 kg/ha of P per hectare was 42 percent as effective and top dressing after emergence was 33 percent as effective as application with the seed. On a silt loam, P content of the grain was not different for 44.8 and 89.6 kg/ha of P. Diammonium phosphate and concentrated superphosphate applied in contact with the seed resulted in high P content than separate placement.

Webb et al. (1961) conducted a field experiment where several slightly water-soluble P sources were compared with concentrated superphosphate for use in broadcast applications for corn. Rates of 33.6 and 67.2 kilograms of available P per hectare were applied on calcareous soils testing low in P. They found that on these calcareous soils a highly water-soluble source of P, such as concentrated superphosphate, is likely to be more effective in broadcast applications for corn than are most slightly soluble sources. If the soil is a high fixing P soil it would be better to band a highly water-soluble phosphate than to broadcast a slightly water soluble phosphate. Soltanpour (1969) in field experiments showed that the placement of fertilizers was crucial for potato production. Uptake of N, P, and Zn when these nutrients were broadcast and disked, was not significantly different from the uptake when no fertilizer was applied to the soil under furrow-irrigation and semi-arid conditions in Colorado. Banding proved to be a more efficient method of apply fertilizers to potatoes. Nitrogen increased P and Zn uptake.

Barber (1958) studied the relationship between row-applied phosphorus and the soil level of available phosphorus in field experiments using a rotation of corn, soybeans, wheat, and hay. High, medium, and low levels of available soil phosphorus were established initially by broadcast applications of superphosphate at rates of 0, 11.2, 28, and

56 kilograms of P per hectare as row fertilizer were superimposed on these soil levels. Results obtained the first 6 years indicate that corn is unable to get the phosphorus it needs from row application to produce maximum yields. Wheat having a smaller row spacing, gave maximum yields with either method of application.

Lawton and Davis (1960) found that uptake of fertilizer phosphorus during the early growth period occurred in seedlings where fertilizer was placed in contact or directly below the seed. In contrast, wheat plants did not absorb an appreciable amount of fertilizer phosphorus from a side placed band until the third week after planting.

Miller and Ohlrogge (1958) in an effort to see the effect of placement of nitrogen fertilizer on the uptake of band placed phosphorus at different soil P levels with corn. In greenhouse studies they found that nitrogen placed with phosphorus in a localized band, increased the relative feeding power of the corn plant on the band phosphorus at soil phosphorus levels of 1 to 2240 kg/ha P. This effect was almost independent of soil phosphate level. Placing nitrogen in a band 7.62 to 10.1 cm from the phosphorus band, increased the relative feeding power of the corn plant on the band phosphorus only at soil phosphate levels of less than 100 kg/ha P. No feeding power increases was observed above this level.

Welch et al. (1966) conducted a study to find the relative efficiency of broadcasting and banding phosphorus for corn. They set up sixteen treatments with four rates of P broadcasted and four banded rates of P on three different soils. They found that the efficiency of broadcast versus banded phosphorus appears to be related to the initial P status of the soil to which P is applied. As the level of P begins to rise to a higher fertility status, the advantages of band application as compared to broadcast application would decrease. They strongly suggest that the choice of broadcasting or banding P is dependent on whether the grower is owner or tenant. If a grower is a tenant he could band the phosphorus and not build the soil status P in case he loses the farm back to the owner and finally the cost of material, time, and application has to be given a lot of consideration.

Murphy et al. (1978) performed studies on dual application of N and P to help point out the value of it. Dual N and P treatments were knifed in and compared to separate knifed in treatments preplant applications of ammonia and broadcast applications of phosphorus. The phosphorus, ammonium polyphosphate, was sprayed on the soil surface and disked in. Results showed that the knifed applications of nitrogen and the phosphorus applied simultaneously produced consistently higher yields than either broadcast or band applications.

Banding starter fertilizers is a well established practice for many crops but Mortvedt (1977) brings a point up we should briefly consider. Poor seedling emergence and subsequent root damage may result when fertilizers with a high salt index are placed too close to the seed row. Since salt concentration increases with decreasing soil moisture, high rates of urea, and diammonium phosphate banded near the seed row also may cause seedling damage from free ammonia or nitrates especially in nuetral and calcareous soils. Moore et al. (1979) performed a study to evaluate the effect that monoammonium phosphate, diammonium phosphate, and urea ammonium polyphosphate have in reducing germination and seedling damage when banded with the seed at nitrogen rates exceeding those where plant seedling or germination damage can occur. All materials were either banded with the seed or broadcast preplant. Results from the study indicate that no severe problem with seedling damage was apparent in the experiment. Some of the treatments showed slight damage at the first of the season but, these differences were gone after three weeks of growth.

Kissel et al. (1980) in a study examined the effect of method of application of N and P on winter wheat growth and yield. They used ammonium polyphosphate and diammonium phosphate at various rates using banded and knifed application of phosphorus. There was a grain response to P fertilizer. Increasing P rates produced high yields. No difference in yield were found due to method of P application although knifed P applications showed higher values of grain nitrogen uptake than banded or broadcast P.

Barber (1976) states that in a soil very low in phosphate it is important to broadcast phosphate in order to have a reasonable supply to all roots. In a study on corn comparing row placement, broadcast, and strip placement of phosphorus fertilizer, they found that strip placement gave the best yield with row placement being next and broadcast last. The band placement has been thought to be the best method but in a low P soil, it is thought that if you increase the band into a strip placement you would get more soil contact to the plant roots and increased uptake resulting in higher yields. Some of the studies showed this to be the case.

New Fertilizer Materials

Researchers in the past few years have started working with liquid fertilizers such as urea ammonium nitrate, ammonium polyphosphate, urea ammonium polyphosphate, and UOP, a material developed by the Tennessee Valley Authority that is an orthophosphate and basically a mixture of urea and phosphoric acid.

Lathwell et al. (1960) compared fertilizers for field crops with dry solid fertilizers. In their experiences, response was similar to P applied from the same material in liquid and solid forms. Response to liquid P was similar in response to solid concentrated superphosphate. Under some conditions response to liquid materials would be greater than that to solid materials containing a rather low water-soluble P.

Cressman et al. (1970) dissolved yellow phosphorus in liquid anhydrous ammonia and evaluated it as a P source for ryegrass and corn. The composition was phytotoxic and the P was of low plant availability. When the solution was incubated in soil prior to seeding corn, toxicity was still present but less severe.

Hill et al. (1973) took phosphorus dissolved in liquid ammonia and got an insoluble, black, phosphorus-rich material. The substance did not inhibit germination or seeding development of sorghum but supplied little phosphate to tomatoes. Leikeam et al. (1979) continued the work with dual injection of anhydrous ammonia and ammonium polyphosphate (10-15-0) elemental form, and urea ammonium nitrate (28-0-0) and ammonium polyphosphate. Dual injection treatments increased yields at all locations. Total N and P content per acre also increased. The percent N in the grain, was lower than with broadcast-disked in treatments. This was offset by higher grain yields. Yields were increased by injecting P regardless of the method of N application.

CHAPTER III

METHOD AND MATERIALS

The method of placement experiments were initiated in the fall of 1980 at four locations across Oklahoma with hard red winter wheat (*Triticum aestivum* L.) as the test crop. The sites selected were representative of large acreages of wheat farming land.

Wheat Studies

The first wheat studies were located in Major County near Orienta, Oklahoma. There were two sites located on one cooperator, one was located west of his house which was called the west place and one was located east of his house which was called the east place. The west place is the (N.W. quarter of the N.E. quarter, Sec. 12, T. 22N., R.12W.). The soil series is a McLain Silty clay loam (fine, mixed (calcareous), thermic Pachic Arguistolls). The soil was extremely clayey and very difficult to work with. The east place is the (S.E. quarter of the N.W. quarter, Sec. 22, T. 22N. R.12W.). The soil series is a Reinach very fine sandy loam (coarse, silty, mixed thermic Pachic Haplustolls). The third site was in Kiowa county near Snyder, Oklahoma, on a cooperators field (S.W. quarter of the S.E. quarter, Sec. 4, T. 2N., R.17W). The soil series is a Miller clay (fine, mixed, thermic, Vertic Haplustolls). The fourth site was at the Eastern Research Station, Haskell, Oklahoma, (N.E. quarter of the S.W. quarter, Sec. 22,

T. 2N., R.17E.). The soil at the Haskell station is a Taloka silt loam (fine, mixed, thermic Mollic Albaqualfs). The fourth location had a rough seedbed so it had to be disk before planting.

All locations had adequate moisture for seed germination, except the Snyder location which stayed extremely dry until February of 1981 at which time it received about 3.8 cm of water by irrigation. The Orienta west place had a poor seedbed, so it was necessary to disk and harrow the field before attempting to plant. This reduced the moisture content and as a consequence the seed did not germinate until the area received its next rainfall.

Almost all fertilizer treatments were applied prior to planting except the treatments where fertilizer was banded with the seed. The experiments were arranged in a randomized block design with fourteen treatments and four replications. The individual plots were 12.2 m long by 6.1 m wide, with 6.1 m alleys at Orienta. The plots at Snyder were 15.2 m long by 6.1 m wide, with 9.1 m alleys. The plots at Haskell were 12.2 m long by 6.1 m wide, with 6.1 alleys.

Table I shows the soil test results of the four location sites. Table II shows the treatments that were applied at all locations. Anhydrous ammonia (82-0-0) and urea ammonia nitrogen (32-0-0) were the sources of N and liquid ammonium polyphosphate (10-15-0) elemental form, and diammonium phosphate (18-21-0) were the P sources. Therefore all treatments that included P also had some N due to the analysis of the P fertilizers. This extra N as well as anhydrous ammonia and urea ammonia nitrogen added up to the total amount of N on all plots excluding the check.

A blanket treatment of 84 kg/ha of anhydrous ammonia was put on all

TABLE I

SOIL TEST RESULTS OF ALL LOCATIONS USED IN WINTER WHEAT STUDIES, 1980

Location	pH	Surface N	P	K
		kg/ha		
Orienta West	7.1	35.8	119.8	640.6
Orienta East	6.6	21.3	52.6	237.4
Snyder	6.5	71.7	127.7	910.6
Haskell	4.5	22.4	90.7	170.2

TABLE II

FERTILIZER TREATMENTS USED IN METHODS STUDY ON WINTER WHEAT, 1980

Treatment No.	Source						Method of Placement
	NH_3 Injected	UAN Broadcast	18-21-0 N	18-21-0 P	10-15-0 N	10-15-0 P	
	kg N/ha		kg/h				
1	0	0	0	0	0	0	
2	84	26.3	0	0	0	0	
3	84	17.6	8.7	10	0	0	P broadcast disked in
4	84	8.7	17.6	20	0	0	P broadcast disked in
5	84	0	26.3	29	0	0	P broadcast disked in
6	84	17.6	8.7	10	0	0	P banded with seed
7	84	8.7	17.6	20	0	0	P banded with seed
8	84	0	26.3	29	0	0	P banded with seed
9	84	19.7	0	0	6.7	10	NH_3-P dual injected
10	84	13.1	0	0	13.2	20	NH_3-P dual injected
11	84	6.6	0	0	19.7	29	NH_3-P dual injected
12	84	19.7	0	0	6.6	10	P banded with seed
13	84	13.1	0	0	13.2	20	P banded with seed
14	84	6.6	0	0	19.7	29	P banded with seed

plots except the check. Urea ammonia nitrogen was used to bring the total amount of N up to 110 kg/ha in each treated plot. The anhydrous ammonia applicator was equipped with five rolling colters with knives directly behind the colters. The colters were spaced 46 cm apart with a stainless steel tube welded to the knife behind the colters for the ammonis to come out. Urea ammonia nitrogen was broadcast sprayed through a spray boom with standard nozzles pressurized by a PTO roller pump. The soil was then harrowed to a depth of 8 to 10 cm. Broadcast treatments of P were applied with a Barber Engineering Company plot fertilizer spreader. All plots were harrowed after treating to a depth of 8 to 10 cm. Dry treatments of diammonium phosphate were banded directly with the seed. A stainless steel tube was mounted directly behind the seed sprout for the APP. The APP was metered out by means of a John Blue Company squeeze pump mounted on the frame of the grain drill. The pump was propelled by a drive chain attached to the seed shaft of the drill. A stainless steel tank was also mounted on the frame to contain the APP. These banded treatments were applied with the seed at planting. The treatments of dual injection (the simultaneous application of anhydrous ammonia and ammonia polyphosphate), were put down with an applicator equipped with five rolling colters, with knives directly behind the colters, the colters are located at 46 cm spacings. Two stainless stell tubes were welded to a knife, one behind the other, with a 2.5 cm space between the tubes to prevent freeze-ups of the APP. Ammonia was injected through the first tube and APP through the second. Fertilizers were injected 15 cm deep. The APP was metered out by means of a John Blue Company squeeze pump mounted on the frame of the anhydrous ammonia applicator. The pump was propelled by a ground drive wheel. A stainless steel tank was also mounted on the frame to contain the APP.

The Orienta east place was planted on October 3, the west place was planted on October 23, and the Snyder location was planted on November 12. They were all sowed with 72.8 kg/ha certified seed. The Haskell location was planted on November 5 with 101 kg/ha of seed. The variety TAM W-101 was used for planting. The wheat studies were planted with a 25 cm spaced hoe type grain drill (LZB1010) made by John Deere.

The only chemical treatment that any of them received occurred in Snyder, where on February 10 they were sprayed with 0.28 kg/ha of MCPA, for control of mustard.

Forage samples were taken from all wheat plots at Haskell and Snyder for N, P, and K analysis as the plants began their active spring growth during the weeks of March 3 - 9. Forage samples were taken by taking 30 square feet off one end of the plots.

The experiments were harvested the last three weeks of June, 1981, using a model "A" Gleaner-Baldwin combine having a three meter header, the center three meters of each plot were cut. The experiments at Haskell and Snyder were 1.5 m shorter in harvest length due to the taking of forage samples. At harvest, grain was collected and weighed for yield, and a sample drawn for chemical analysis of N, P, and K concentrations.

Laboratory Data

Forage and grain samples were analyzed for N, P, and K concentration. The N was analyzed by performing a sulfuric acid digestion, followed by the Micro-Kjeldahl method, and the P and K by a nitricperchloric digestion, followed by a colorimetric determination for P content and the analysis of K by atomic absorption. All procedures are standard laboratory procedures of the Oklahoma State University Agronomic Services.

Method of Data Evaluation

All statistical work was done through the University Computer Center, and analyzed with the Statistical Analysis System (SAS79). Analysis of variance procedures were used to determine if treatment effects were significant at the .05 level of probability for grain yield, and for differences in the N, P, and K content of forage and grain. The comparisons of means were accomplished by using the protected least significant difference (LSD) procedure. This procedure implies that the "F" value for treatments will be compared by the conventional LSD procedure. Duncan's new multiple-range test was used to show a grouping of means and treatments to find out where the differences were as suggested by Snedecor et al. (1967).

CHAPTER IV

RESULTS AND DISCUSSION

Wheat Studies

Grain was the only harvest data at the Orienta west place in 1981. Grain parameters for this location are reported in Table III. Of all the grain parameters measured none of the treatments were significantly different at the .05 level. Although where P was injected yields were higher.

The Orienta west place had a bad seedbed and the stand of wheat was not normal throughout the growing season until harvest. This location stayed extremely dry and along with the poor stand, this could contribute to the fertilizer in the treatments not being utilized.

At the Orienta east place grain was the only data collected and parameters are reported in Table IV. Grain yield and grain nitrogen uptake were the only two parameters that were significantly different at the .05 level. Check plot grain yield was significantly lower than all treatments. Although not significant at 0.05 level, injection treatments of P tended to yield higher. Grain nitrogen uptake was also significantly higher than the check. This location was heavily grazed and this may be the reason why treated plots were different from the check.

The Snyder location had both forage and grain harvest. Forage data is reported in Table V and grain data is reported in Table VI.

TABLE III

GRAIN YIELD, GRAIN UPTAKE AND PERCENT GRAIN N, P, AND K FROM METHODS STUDY ON WINTER WHEAT, ORIENTA WEST, 1980-1981

	Treatment Method	N Rate	P Rate	Yield	N	P	K	N	P	K
		kg/ha		kg/ha				%		
1.	Check	0	0	2543	69	12	12	2.71	0.46	0.49
2.	N	110	0	2836	78	12	14	2.78	0.44	0.49
3.	N, P (18-21-0) broadcast disked in	110	10	3007	84	13	15	2.79	0.44	0.49
4.		110	20	2461	63	11	12	2.62	0.46	0.48
5.		110	29	2574	72	12	13	2.80	0.47	0.52
6.	N, P (18-21-0)	110	10	2671	76	12	13	2.84	0.44	0.50
7.		110	20	2994	82	13	14	2.73	0.42	0.45
8.		110	29	2610	74	12	13	2.84	0.45	0.49
9.	N, P (10-15-0) dual injected	110	10	2878	81	12	13	2.83	0.42	0.47
10.		110	20	2723	74	12	12	2.77	0.44	0.46
11.		110	29	3013	84	14	15	2.80	0.45	0.49
12.	N, P (10-5-0) banded with seed	110	10	2592	79	11	12	3.08	0.44	0.47
13.		110	20	2763	79	12	13	2.86	0.44	0.47
14.		110	29	2677	78	12	12	2.92	0.43	0.46

Protected LSD (.05) = No Significant Differences (NSD)

TABLE IV

GRAIN YIELD, GRAIN UPTAKE AND PERCENT GRAIN N, P, AND K FROM METHODS STUDY ON WINTER WHEAT, ORIENTA EAST, 1980-1981

Treatment Method		N Rate	P Rate	Yield	N	P	K	N	P	K
		kg/ha	kg/ha	kg/ha				%		
1.	Check	0	0	1415	30	6	5	2.03	0.41	0.37
2.	N	110	0	2028	50	8	7	2.46	0.39	0.35
3.	N, P (18-21-0) braodcast disked in	110	10	2043	53	9	7	2.57	0.42	0.37
4.		110	20	1881	50	8	7	2.69	0.41	0.36
5.		110	29	1906	49	8	7	2.58	0.43	0.38
6.	N, P (18-21-0) banded with seed	110	10	1921	46	8	7	2.38	0.40	0.36
7.		110	20	2046	55	8	7	2.66	0.38	0.35
8.		110	29	1988	47	8	7	2.37	0.39	0.35
9.	N, P (10-15-0) dual injected	110	10	1912	51	8	7	2.69	0.41	0.36
10.		110	20	2141	55	9	8	2.58	0.42	0.37
11.		110	29	1912	50	8	7	2.63	0.43	0.36
12.	N, P (10-15-0) banded with seed	110	10	2034	48	8	7	2.38	0.41	0.36
13.		110	20	2101	46	8	7	2.20	0.37	0.34
14.		110	29	2104	54	8	7	2.59	0.39	0.35
	Protected LSD (.05)			303	11	NSD	NSD	NSD	NSD	NSD

TABLE V

FORAGE DRY MATTER YIELD, PERCENT DRY MATTER, FORAGE N, P, AND K UPTAKE AND PERCENT N, P, K FROM METHODS STUDY ON WINTER WHEAT, SNYDER, 1980-1981

Treatment Method		N Rate	P Rate	Dry Matter Yield	N	P	K	Dry Matter	N	P	K
		kg/ha		kg/ha				%			
1.	Check	0	0	929	32	3.36	32	21	3.34	0.37	3.43
2.	N	110	0	1353	53	4.68	55	19	3.88	0.34	4.09
3.	N, P (18-21-0) broadcast disked in	110	10	1660	64	5.68	60	19	3.90	0.34	3.62
4.		110	20	1320	52	4.45	54	20	4.04	0.34	4.22
5.		110	29	1439	57	5.09	56	19	4.02	0.36	3.94
6.	N, P (18-21-0) banded with seed	110	10	1729	68	6.46	74	19	3.92	0.38	4.35
7.		110	20	1362	52	4.69	52	20	3.72	0.34	3.75
8.		110	29	1370	55	4.92	53	19	4.02	0.35	3.91
9.	N, P (10-15-0) dual injected	110	10	1161	46	4.34	44	20	3.98	0.37	3.79
10.		110	20	1620	62	6.05	65	20	3.86	0.38	4.11
11.		110	29	1448	55	5.63	54	19	3.78	0.39	3.68
12.	N, P (10-15-0) banded with seed	110	10	1557	59	5.51	61	19	3.77	0.35	3.92
13.		110	20	1449	60	5.37	61	19	3.84	0.35	3.89
14.		110	29	1985	75	6.63	79	19	3.84	0.34	3.99
	Protected LSD (.05)			621	21	2.09	24	NSD	NSD	NSD	NSD

TABLE VI

GRAIN YIELD, GRAIN UPTAKE AND PERCENT GRAIN N, P, AND K FROM METHODS STUDY ON WINTER WHEAT, SNYDER, 1980-1981

Treatment Method	N Rate	P Rate	Yield	N	P	K	N	P	K
	kg/ha		kg/ha				%		
1. Check	0	0	2824	65	15	15	2.30	0.52	0.53
2. N	110	0	2599	72	13	13	2.81	0.50	0.52
3. N, P (18-21-0) broadcast disked in	110	10	2727	77	14	15	2.82	0.50	0.54
4.	110	20	2576	75	13	13	2.91	0.51	0.53
5.	110	29	2437	68	13	13	2.79	0.52	0.51
6. N, P (18-21-0) banded with seed	110	10	2561	71	12	13	2.77	0.47	0.50
7.	110	20	2569	73	13	12	2.84	0.49	0.48
8.	110	29	2767	76	13	14	2.74	0.49	0.50
9. N, P (10-15-0) dual injected	110	10	2567	70	13	14	2.74	0.51	0.54
10.	110	20	2466	69	13	13	2.80	0.51	0.54
11.	110	29	2775	76	14	14	2.74	0.50	0.51
12. N, P (10-15-0) banded with seed	110	10	2643	75	13	14	2.83	0.51	0.51
13.	110	20	2792	76	13	14	2.73	0.48	0.49
14.	110	29	2865	82	14	14	2.86	0.50	0.49
Protected LSD (.05)			NSD	NSD	NSD	NSD	0.16	NSD	NSD

Nitrogen, phosphorus, and potassium in forage dry matter were the only parameters significantly different at the .05 level. Treatments where P was injected regardless of P rate or method of placement gave higher dry matter yields than the check. Nitrogen uptake in treatments where P was injected regardless of rate yielded higher yields than when the P was broadcast, the check and the straight N plots yielded the least nitrogen uptake in dry matter. Concerning P uptake treatments where P as APP was injected yielded higher P uptake than treatments where dry P was injected or broadcast yielded higher K uptake than the check or the straight N plots. In these parameters the highest yields occurred with the highest two P rates, 20 and 29 kg/ha.

At Snyder the only grain parameter that was significantly different at the .05 level was percent grain nitrogen. The check was significantly lower than the rest of the treatments. The highest yields were obtained when N and P were both applied, regardless of method or rate. The Snyder location had adequate moisture through irrigation.

The Haskell location had both forage and grain harvest and the results are reported in Table VII for forage and Table VIII for grain. At Haskell all the forage parameters measured were significantly different at the .05 level. The check, the straight nitrogen, and the broadcast P disked in treatments in most parameters measured yielded the least quantities. Treatments where P was injected yielded the greatest quantities, in these treatments no method or rate of P predominated.

Grain yield, grain N uptake, and percent grain N, P and K were significantly different at the .05 level at Haskell. Treatments where P as APP was injected produced the highest grain yields, than any other of the methods, regardless of P rate. Concerning grain N uptake where P

TABLE VII

FORAGE DRY MATTER YIELD, PERCENT DRY MATTER, FORAGE N, P, AND K UPTAKE AND PERCENT N, P, K FROM METHODS STUDY ON WINTER WHEAT, HASKELL, 1980-1981

	Treatment Method	N Rate	P Rate	Dry Matter Yield	N	P	K	Dry Matter	N	P	K
		kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha	%	%	%	%
1.	Check	0	0	590	23	1.38	21	22	3.86	0.23	3.40
2.	N	110	0	528	24	1.22	19	21	4.53	0.22	3.56
3.	N, P (18-21-0) broadcast disked in	110	10	988	42	2.49	34	20	4.36	0.24	3.37
4.		110	20	1135	51	3.22	39	19	4.51	0.28	3.37
5.		110	29	1196	55	3.75	44	19	4.61	0.31	3.54
6.	N, P (18-21-0) banded with seed	110	10	1138	60	3.78	43	19	4.49	0.28	3.12
7.		110	20	1411	65	4.76	43	18	4.62	0.33	2.97
8.		110	29	1573	71	5.43	45	18	4.57	0.35	2.84
9.	N, P (10-15-0) dual injected	110	10	786	37	2.49	25	19	4.80	0.32	3.14
10.		110	20	769	39	2.89	25	18	5.09	0.38	3.21
11.		110	29	1261	61	5.29	42	17	4.89	0.42	3.22
12.	N, P (10-15-0) banded with seed	110	10	1457	69	4.90	46	18	4.72	0.33	3.17
13.		110	20	1743	74	5.30	55	18	4.33	0.30	3.14
14.		110	29	1259	58	3.87	42	19	4.66	0.31	3.30
	Protected LSD (.05)			443	20	2.00	16	2	0.28	0.05	0.32

TABLE VIII

GRAIN YIELD, GRAIN UPTAKE AND PERCENT GRAIN N, P, AND K FROM METHODS STUDY ON WINTER WHEAT, HASKELL, 1980-1981

Treatment		N	P							
	Method	Rate		Yield	N	P	K	N	P	K
		kg/ha		kg/ha				%		
1.	Check	0	0	2823	58	6.74	7.55	2.66	0.31	0.34
2.	N	110	0	2544	61	4.72	5.58	3.09	0.24	0.28
3.	N, P (18-21-0) broadcast disked in	110	10	2805	66	6.00	6.64	3.01	0.27	0.30
4.		110	20	3171	74	5.99	7.06	3.02	0.24	0.29
5.		110	29	3129	74	6.26	7.25	3.06	0.26	0.30
6.	N, P (18-21-0) banded with seed	110	10	2980	71	5.36	6.57	3.08	0.23	0.28
7.		110	20	2805	66	5.15	6.15	3.06	0.24	0.28
8.		110	29	2648	64	4.55	5.29	3.10	0.22	0.26
9.	N, P (10-15-0) dual injected	110	10	2666	64	5.36	6.11	3.11	0.26	0.29
10.		110	20	2387	62	5.20	5.75	3.34	0.28	0.31
11.		110	29	2718	65	5.66	6.69	3.08	0.27	0.32
12.	N, P (10-15-0) banded with seed	110	10	2770	68	4.98	5.68	3.15	0.23	0.26
13.		110	20	2980	70	5.42	6.11	3.05	0.23	0.26
14.		110	29	2892	67	5.56	6.11	2.98	0.25	0.27
	Protected LSD (.05)			416	9	NSD	NSD	0.23	0.04	0.04

was injected regardless of rate or method produced higher yields than the check or straight N treatment. The check is different from all other treatments in percent grain N, where P was put down with N yielded the greatest percent N regardless of P rate. On percent P and K of the grain the check out yielded other treatments, this might be accounted for in the medium to high soil test of P at this location. Potassium was relatively low at Haskell so why the check produced the greatest percent grain K is difficult to understand.

Wheat Studies Combined

When the Snyder and Haskell locations were combined there were differences in forage variables. Dry matter yield and percent forage N and P were the only parameters significantly different at the .05 level. In dry matter the check, straight N, and the dual injected P produced the lowest yields. When P in either dry or liquid form was banded with the seed the greatest yields occurred regardless of reate of P banded. Forage percent N was significant at the .05 level with the check producing the least percent of N taken up than any other treatment, with no one method or rate of P predominating. Forage percent K was significantly different at the .05 level with the check and broadcast treatments producing the least amount of percent K taken up. The highest percent P was achieved when P was banded or injected with N regardless of rate. Forage results for combined locations, Snyder and Haskell are reported in Table IX.

All wheat grain variables at all locations, Snyder, Haskell, Orienta West, and Orienta East were combined for statistical analyses. Grain variables were significantly different when statistically analyzed

TABLE IX

FORAGE DRY MATTER YIELD, PERCENT DRY MATTER, FORAGE N, P, AND K UPTAKE AND PERCENT N, P, K FROM METHODS STUDY ON WINTER WHEAT, SNYDER AND HASKELL COMBINED, 1980-1981

	Treatment Method	N Rate	P Rate	Dry Matter Yield	N	P	K	Dry Matter	N	P	K
		kg/ha		kg/ha				%			
1.	Check	0	0	759	27	2	26	22	3.40	0.30	3.41
2.	N	110	0	940	38	3	37	20	4.21	0.28	3.83
3.	N, P (18-21-0) broadcast disked in	110	10	1324	53	4	47	20	4.13	0.29	3.50
4.		110	20	1228	51	4	47	20	4.28	0.31	3.79
5.		110	29	1317	56	4	50	19	4.31	0.32	3.74
6.	N, P (18-21-0) banded with seed	110	10	1533	64	5	59	19	4.20	0.33	3.73
7.		110	20	1387	58	5	47	19	4.17	0.34	3.36
8.		110	29	1472	63	5	49	18	4.29	0.35	3.37
9.	N, P (10-15-0) dual injected	110	10	973	42	3	35	19	4.39	0.35	3.47
10.		110	20	1083	45	4	41	17	4.48	0.38	3.66
11.		110	29	1165	49	5	40	16	4.34	0.40	3.45
12.	N, P (10-15-0) banded with seed	110	10	1506	64	5	54	19	4.24	0.34	3.54
13.		110	20	1645	67	5	58	19	4.09	0.32	3.51
14.		110	29	1514	62	5	57	17	4.25	0.33	3.64
	Protected LSD (.05)			464	NSD	NSD	NSD	NSD	0.20	0.03	NSD

by location but grain yield was the only grain variable that was significantly different at the .05 level when the location, treatment interaction was accounted for. Grain yield results are presented in Table X. As an overview treatments concerning location, treatment interaction when P was banded with the seed or broadcast disked in the highest yields with the check treatment producing the least yield.

TABLE X

GRAIN YIELD, GRAIN UPTAKE AND PERCENT N, P, AND K FROM METHODS STUDY ON WINTER WHEAT, ALL LOCATIONS COMBINED, 1980-1981

	Treatment Method	N Rate	P Rate	Yield	N	P	K	N	P	K
		kg/ha		kg/ha				%		
1.	Check	0	0	40	59	10	11	2.42	0.42	0.43
2.	N	110	0	42	70	10	10	2.78	0.39	0.41
3.	N, P (18-21-0) broadcast disked in	110	10	44	74	11	11	2.80	0.41	0.43
4.		110	20	42	71	10	10	2.81	0.41	0.41
5.		110	29	42	71	10	11	2.81	0.42	0.43
6.	N, P (18-21-0) banded with seed	110	10	42	71	10	10	2.77	0.38	0.41
7.		110	20	43	74	10	10	2.82	0.38	0.39
8.		110	29	42	70	10	10	2.76	0.39	0.40
9.	N, P (10-15-0) dual injected	110	10	42	71	10	10	2.84	0.40	0.41
10.		110	20	40	69	11	10	2.87	0.41	0.42
11.		110	29	43	73	10	11	2.81	0.41	0.42
12.	N, P (10-15-0) banded with seed	110	10	42	72	10	10	2.86	0.40	0.40
13.		110	20	44	73	10	10	2.71	0.38	0.39
14.		110	29	44	75	10	10	2.84	0.39	0.39
	Protected LSD (.05)			3	NSD	NSD	NSD	NSD	NSD	NSD

CHAPTER V

SUMMARY AND CONCLUSIONS

Studies on wheat at four locations were devised to help determine the best and most economical method of phosphorus placement. Dual injection of anhydrous ammonia and ammonia polyphosphate (APP, 10-15-0) and banding dry diammonium phosphate (DAP, 18-21-0) or banding liquid APP with the seed were compared against the more conventional method of fertilizer application, broadcasting phosphorus and incorporating it into the soil. To determine fertilizer method efficiency yield of grain and forage nutrient concentration and uptake in both the forage and grain were analyzed.

Each location was analyzed separately and then in combined analysis to determine the best method of P placement for different parts of the state.

The following conclusions have been reached from the wheat studies.

Wheat Study

Statistical analysis of the forage data at Haskell and Snyder shows that there are differences in all forage parameters due to location. Where the location-treatment interaction occurred percent forage N and P were significantly different at the .05 level between treatments. The treatments where the NH_3 and APP were dual injected or P was banded with the seed regardless of rate produce the highest percent N, P, and K in forage and the checks usually produced the least.

Statistical analysis of the grain data at all locations shows that all the grain variables were different due to location.

The location treatment interaction of all locations statistically shows a very significant difference between all treatments to the check and the straight N treatment. The treatments where the P was banded with the seed regardless of rate produced the most grain yield with the check or the straight N treatment producing the least.

Where all locations were combined the location-replication interaction was statistically different in almost all of forage and grain variables measured. The differences for this can be accounted for from several sources. The fertility of the soil at all locations was adequate for wheat production with maybe the exception of surface nitrogen at some locations. The replication-location differences could be caused by different soil types within each experiment acting differently to the fertilizer materials available. The growing season of 1980-81 was extremely dry at three of the four locations, a stand of wheat was established on these locations but, the wheat did not start growing until late January. The extended period of dryness could have helped inhibit the fertilizer from being utilized by the wheat plant.

In Oklahoma if the soil test P is low or medium it could be more advantageous to place or band P with the seed regardless of what part of the state it is in. In using dual injecting and banding with the seed one would have a trip in putting the N and P down at the same time or in putting the P down at planting.

Suggestions for Further Research

More detailed research of the movement of P in a dual injection zone compared to injecting P alone may shed some light on the problem of finding the right method of placing P. The enhanced uptake of P in forage with dual injection indicates that some factor is causing P to be more available to the plant.

Further field work also needs to be conducted along the lines as this study, to determine effects of dual injection space and banding P with the seed over a long period of time.

Minimum tillage should be looked at in the field possibly as combining fewer tillage operations before the next crop as well as putting N and P down, if something like a Noble blade was used.

The author feels that dual injection of N and P as well as banding P with the seed should not be overlooked, especially if fuel and fertilizer keep rising in price.

The price of fertilizer materials, time limit, and soil test should be the deciding factors for placement of P.

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