EFFECT OF DUAL INJECTION OF NITROGEN AND PHOSPHORUS ON GRAIN SORGHUM AND WINTER WHEAT

By

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CHAPTER I

INTRODUCTION

Conservation of our non-renewable natural resources must play a vital role in our continuing search for better and more efficient agricultural methods. This study is devoted to that end, because it strives to show that both fuel and fertilizer can be utilized more efficiently to obtain the same, or better results as more conventional methods of fertilizer application. Dual injection is also perfectly suited to no-till or minimum till practices, which in turn reduces the great hazard of soil erosion.

In this study, dual injection refers to the simultaneous injection of anhydrous ammonia and liquid ammonium polyphosphate through adjacent tubes behind a knife, thereby banding the two materials in direct contact with one another.

Agronomists have long noticed the beneficial effect of placing N and P in direct contact with each other in a band placement scheme, yet this method has not been widely practiced. However, with the fertilizer materials now available for general use, a viable alternative to agronomic practices that require high amounts of energy now being employed has come to the forefront. With the use of relatively cheap anhydrous ammonia and the liquid polyphosphates on the market, time, money, and resources may be saved by reducing the number of trips across a field, and reducing the amount of phosphate used.

With this in mind, experiments were designed to test the efficiency of dual injection. The specific objectives of the study were 1) to determine if the placement of ammonium polyphosphate (APP) in relation to the placement of anhydrous ammonia (NH_3) plays a role in the efficiency of phosphorus uptake in certain Oklahoma soils; 2) to ascertain whether this effect is manifested in yield of grain, and forage and grain N and P content; 3) to a lesser extent in this study, to observe if dually injected N and P results in greater P availability in the zone of injection as opposed to P injected without N.

CHAPTER II

REVIEW OF LITERATURE

Effect of Nitrogen on Phosphorus Uptake

Researchers have substantiated the fact that nitrogen, particularly the ammonium form, increases plant absorption of soil and fertilizer phosphorus. Smith et al. (1950) performed a study on nitrogen and phosphorus, and found that applications of both fertilizers gave highly significant increases in the percent of fertilizer taken up by the plant, using forage oats. The maximum increase occurred when the highest rates of N and P were applied.

In an experiment with nitrogen source and its effect on available phosphorus, Lorenz and Johnson (1953) found ammonium to be a more effective source of N than nitrate. Experimenting with tomatoes in the greenhouse, they found that the ammonium fertilized plants at low phosphate fertilization rates yielded more than double the fresh weight of those fertilized with nitrate. At high P rates, the nitrate treatment did better than the ammonium treatment. Plants fertilized with no or very low (5 ppm) P and nitrate showed severe P deficiencies, whereas those fertilized with ammonium sulfate never displayed a P deficiency.

Robertson et al. (1954) also found that nitrogen, especially ammonium, increased the rate of uptake of phosphorus. When N plus P were banded at a high rate, it significantly increased the percentage of P in the plant from fertilizer and doubled the recovery of fertilizer by the plant. These increases were associated with a fourteen bushel increase in yield of corn.

Olsen and Dreier (1956a) report that the placement of a N-P fertilizer together, away from the seed, provided twice the yields of small grains than did either fertilizer alone. They stress that supplemental nitrogen is essential to maximum phosphorus utilization.

Further work done in Nebraska by Olsen and Dreier (1956b) points to a nitrogen-phosphorus relationship also. They say that yield increases for each of the fertilizer elements alone do not aggregate the increase from nitrogen-phosphorus treatments. A very important reason is an enhanced utilization of fertilizer P occasioned by the presence of fertilizer N. Their greenhouse work showed that the greatest enhancement of phosphorus uptake occurred when N and P were placed in contact with each other.

Werkhoven and Massantini (1967) studied the effects of nitrogen and phosphorus placement. Using one level of ammonium nitrate and three levels of monocalcium phosphate on safflower, they either banded them together, broadcast both of them, or banded one while broadcasting the other. In general, they found that broadcasting the P was not as effective as banding it. Band placement of 28 kg P/ha was as efficient as broadcasting twice that amount. Placement of N was less important, but the placement of N with P produced yields that were not significantly higher (.05 level), even though some increases were observed.

pH Effects

The addition of ammoniacal N to the soil will cause a subsequent 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 N, the ammonium sulfate would have a greater acidifying effect than ammonium nitrate. Preferential absorption by the plant of the rapidly absorbable ammonium ions over the slowly absorbable sulfate ions would also tend to lower the soil pH.

Lorenz and Johnson (1953) suggest that the reason ammonium sulfate promotes increased P uptake is because ammonium in the soil has an acidic reaction which renders the soil P more soluble and available for plant use. They used a soil that was calcium dominated (Hesperia fine sandy loam) and feel that the acidity produced through nitrification was the cause of the increased solubility of P.

From a physiological standpoint, plants appear to absorb more P at a lower pH. Hagen and Hopkins (1955) found that excised barley roots generally absorbed more P at pH 5.0 than at higher pH levels.

They found that hydroxyl ions competitively inhibited absorption of both $H_2PO_4^-$ and HPO_4^- ions.

Breon et al. (1944) presents us with another viewpoint, however. In these experiments, tomato plants grown in medium supplying urea as source of N did not develop deficiency symptoms due to a lack of P as soon as did plants which received nitrate N. This held true for both pH 4.8 - 5.0 and pH 6.8 - 7.0, although those plants at the higher pH did not show as marked a delay in displaying P deficiencies as those at the lower pH. Plants furnished with urea grew much better at the higher pH. The tomato plants that received urea absorbed P at a greater rate than those that received nitrate N.

Chapman (1935) was concerned mainly with the solubility of phosphorus due to concentrations of hydrogen and calcium in the soil. He found that with plants fertilized with various nitrogen carriers, quite a difference in phosphate uptake occurred. The greatest effect on growth aside from that resulting from direct application of P to the soil, came with the use of nitric acid. Ammonium sulfate, ammonium nitrate, and urea all produced significant increases over calcium nitrate on two high phosphorus soils, but had no effect on two low P soils.

Grunes et al. (1958a) provide some contradictory data to what Chapman reported, although they were working with added P and Chapman was not. Working with barley in the greenhouse, they report that when all fertilizers were banded, ammonium sulfate banded with P was the most effective for phosphorus uptake while nitric acid and sulfuric acid tended to decrease the percent of P absorbed by the plants from the fertilizer. They also found that the addition of either ammonium sulfate or sodium nitrate increased the percent of the total P absorbed by the plants from the fertilizer. The ammonium sulfate was more effective than the sodium nitrate, however. The ammonium sulfate appears to increase the availability of P to the plant. Increased root growth was also noted with the banded fertilizer.

Olsen and Dreier (1956b) claim in their experiments that there is no benefit of acidifying substances applied for promoting fertilizer phosphorus utilization. It also appears that the sulfate ion is not a factor in the enhancement of fertilizer P solubility by ammonium sulfate on acid soils.

Caldwell (1960), using ^{32}P, found that salts such as ammonium nitrate, ammonium sulfate, and ammonium chloride increased P absorption greatly, but only when the P and N were mixed together. N in ammonium phosphate also increased P uptake. Calcium nitrate and sodium nitrate did not increase P absorption.

Bouldin and Sample (1959) showed that movement of P in the soil was not altered by the presence of calcium or ammonium. They made pellets of monocalcium phosphate and mono- and di-ammonium phosphates and measured the distribution of the soil-fertilizer P reaction products. They used two different soils, and found that whereas the soil type affected movement significantly, the source of the phosphate had little or no effect on movement.

Maramil and Miller (1970) performed tests to see if like elements in the periodic table would act as P in the presence of ammonium. Using rubidium and sulfate, they found that ammonium did not influence the uptake of these ions.

Werkhoven and Miller (1960) did some work concerning N and P placement on sugar beets. In general, the absorption of fertilizer P was affected more by the placement of N relative to the placement of P than merely by the placement of P. The influence of placement of both N and P increased with time, being greatest at the last determination. Their results showed that placing N and P together resulted in greater P uptake than did mixing either or both with the soil.

Miller et al. (1970) stated the cause of increased P uptake with ammonium fertilizers can be attributed not to a general lowering of the pH, but to pH changes as they relate to P precipitation at the soil-root interface. By taking photographs and autoradiographs of P precipitation on the root surfaces, the accumulation of P in the absence of ammonium is clearly seen. Washing off the root surface, there was six times as much P on the root surface than inside the root using monocalcium phosphate (MCP) than with MCP plus ammonium sulfate. Further, the accumulation of P on the root was clearly associated with the calcium present. It too was precipitated. The pH of the roots and adhering soil removed in the vicinity of the fertilizers was lowest with the MCP plus ammonium sulfate treatment and highest with MCP alone.

Blair et al. (1971) showed that the application of nitrate N with P would increase P accumulation on the root surface and decrease P uptake. The opposite was observed with ammonium. They used ^{32}P to determine P uptake in corn, and found that when differences in top growth were evident nine days after sowing, the activity in the plants was highest using P plus NH_4^+, intermediate with P alone, and lowest with P plus NO_3^-. This effect was most significant in soils with high pH.

Riley and Barber (1971) performed similar tests. Using the same soil throughout, they induced pH changes by applying lime. When using an ammoniacal fertilizer, nitrapyrin inhibited nitrification to minimize effects of hydrogen ions. At all pH levels, P content was significantly higher when ammonium rather than nitrate was used. All fertilizers were broadcast.

Uptake Due to Increased Root Growth

Many researchers believe increased root growth is a primary cause of better absorption of P in the presence of N. Grunes et al. (1958a) noted that wherever N and P were banded together, the proportion of roots in the fertilizer band was considerably higher than for the P alone treatment. Total plant phosphorus was increased more by banding ammonium sulfate with the P than the nitrate source. There was a decrease in the pH in the barley rooting zone where ammonium was applied.

Grunes et al. (1958b) followed up the greenhouse work on barley with field work on sugar beets and potatoes. On sugar beets, they found that the addition of ammonium nitrate increased the percentage of total P absorbed. The same results were obtained with potatoes. An increase of root growth was noted in each case.

Duncan and Ohlrogge (1958) give strong evidence toward the root growth theory. They divided the root systems of young corn plants in joined containers with different fertilizer treatments. One of the sides was untreated, the other treated with either N, P, or N + P. Root weights show clearly that N + P treatments induce root development. P and N additions alone had a less pronounced effect. They point out that the roots developed in the N + P soil were much finer and silkier in appearance, and that the number of roots was obviously much greater.

Miller and Vij (1962) used pellets made from either P alone or P and ammonium sulfate to try to generate results regarding sugar beet root mass increases. The weight of the roots in the band volume at the eight and ten week stages was doubled by the addition of ammonium sulfate to the P band.

Werkhoven and Miller (1960) present some data on N source and placement with P on sugar beets. They concur with the other data that points to increased P uptake when the N and P are placed together, particularly the ammonium form. However, depending upon the depth of placement, the rate of P uptake differs. They believe this differential response with depth of placement is more likely a result of increased root growth than efficiency due to N.

Physiological Effects of NH_4^+ on the Root

Willis and Yemm (1955) reported that the respiratory activity of detached barley roots increased when these roots were treated with ammonium and nitrate salts. 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.

Rennie and Soper (1958) designed an experiment in the greenhouse to see if an acid salt other than ammonium sulfate would also enhance the uptake of P. Mixing the acid salt $KHSO_4$ with monoammonium phosphate did not bring about an increase of P uptake, but a decrease. The addition of nitrate was ineffective, and the addition of ammonium was effective.

Miller (1965) claims that ammonium exerts a specific influence on the physiological activity that controls P absorption. He used a single seminal corn root for observation.

Leonce and Miller (1966), using ^{32}P, made a pellet containing phosphorus and either ammonium sulfate, ammonium chloride, or potassium nitrate. While both the ammonium sources did better than the nitrate, the sulfate salt appears to be a better source than the chloride. Autoradiographs taken several times during the experiment indicated a concentration of labelled P in the roots of the P only treatment and the nitrate plus P treatment. No such accumulation showed up in the other treatments. They conclude it is apparent the ammonium increased the transfer of P from the root to the top. By placing the two elements apart, the same effect was not observed. Therefore, for the increase in absorption to occur, the N and P need to be present at the same point on the root.

Thein and McFee (1970) pretreated corn seedlings with N plus ^{32}P, ^{32}P, and water for 24 hours. Plants were then transferred to treatment solutions containing either N + P or P. Uptake and translocation of the labelled P was monitored. They found that the N pretreatments significantly increased P uptake and translocation rates during the following six hours. This was not observed with the pretreatment lacking N. They claim this indicates no companion effect of N and P movement into cells. They suggest the existence of a N requiring metabolite for efficiency of P absorption in corn. No significant difference between NO_3^- and NH_4^+ were observed.

Newer Fertilizer Materials

In an effort to create a new fertilizer, Cressman et al. (1970) experimented with anhydrous ammonia and phosphorus. Yellow phosphorus was dissolved in liquid NH_3 and evaluated as a fertilizer source for corn and ryegrass. The composition was phytotoxic and the P of low plant availability. When the solution was incubated, phytotoxicity was less severe but still present.

Hill et al. (1973) followed up on this experiment to report the effectiveness of NH_3-P residue as a phosphatic fertilizer in alkaline and limed soils. Sorghum seeds germinated with it and no chlorosis was noted. The roots, however, grew around and not into the band of NH_3-P. Tomatoes grown in this manner were found to be slightly chlorotic.

Murphy et al. (1978) performed tests in Kansas involving NH_3 and liquid ammonium polyphosphate (10-15-0). Using dual knifing techniques to apply the fertilizers simultaneously, consistently higher yields of wheat were produced than with either broadcast or separate band applications.

Leikam et al. (1979) continued the work with dual injection of NH_3-APP, and UAN (urea ammonium nitrate, 28-0-0)-APP. Dual injection treatments increased yields at all locations tested. The total N and total P content per hectare in the grain was also greater, although the percent N in the grain was lower than with broadcast-disk in treatment. This was offset by the higher grain yields. Percent P remained relatively constant no matter what the treatment. Yields were generally increased by injecting the P regardless of the method of application of N.

CHAPTER III

METHODS AND MATERIALS

The dual injection experiment consisted of two phases. The preliminary study was performed during the summer of 1979 at two locations in western Oklahoma, with grain sorghum (Sorghum bicolor L.) as the test crop. This preliminary study allowed us to work out many of the idiosyncracies of the technique and equipment that was utilized.

The second phase of the experiment was initiated in the fall of 1979 at three locations across Oklahoma with hard red winter wheat (Triticum aestivum L.). The sites selected were representative of large acreages of wheat farming land in certain sections of the state.

Sorghum Studies

The first sorghum study was located in Major County near Orienta, Oklahoma (N.W. quarter, Sec. 14, T. 22N., R.13 W.). The soil series is a Treadway clay (fine, mixed (calcareous), thermic Vertic Torrifulents). This soil was extremely clayey and very difficult to work with. The second site was in Roger Mills County near Berlin, Oklahoma (N.E. quarter, Sec. 35, T. 11N., R.23 W.). The soil is described as a Dill fine sandy loam (coarse-loamy, mixed, thermic Udic Ustochrepts). Both locations had adequate moisture for seed germination, but the Major County location 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.

All fertilizer treatments were applied prior to planting. The experiment was arranged in a randomized complete block design, with ten treatments and four replications. The individual plots were 12.2 m long by four 100 cm rows wide, with 6.1 m alleys. One exception to alley length was plotted at the Major County location because there was a sandy spot within the experimental site. The fourth replication was 41.1 m from the third. This is important, because during August, a localized rainstorm dropped rain on the first three replications, and the fourth received no moisture. That replication was not used in the analysis.

Table I shows the treatments that were applied at both locations. Anhydrous ammonia was the source of N and liquid APP was the source of P (10-15-0). Therefore all treatments that included P also had some N due to the analysis of the fertilizer.

The fertilizers were applied one of two ways. In broadcast treatments, the liquid APP was sprayed through a spray boom with standard nozzles and pressurized by a PTO roller pump. The soil was then disked to a depth of 12.5 to 15 cm. The anhydrous ammonia applicator was equipped with five rolling coulters, directly behind which the knives were located, at 45 cm spacings. Two stainless steel tubes were welded to a knife, one behind the other, with a space between the tubes of 2.5 cm to prevent freeze-ups of the APP. NH_3 was injected through the first tube and APP through the second. The fertilizer was injected 15 cm deep. The APP was metered out by means of a John Blue Company squeeze pump mounted on the frame of the

TABLE I

FERTILIZER TREATMENTS USED IN DUAL INJECTION STUDY ON GRAIN SORGHUM, 1979

Treatment No.	kg/ha N Broadcast	kg/ha N Injected	kg/ha P Broadcast	kg/ha P Injected
1	0	0	0	0
2	6.7	0	9.8	0
3	13.4	0	19.6	0
4	0	6.7	0	9.8
5	0	13.4	0	19.6
6	0	90	0	0
7	6.7	90	9.8	0
8	13.4	90	19.6	0
9	0	90 + 6.7	0	9.8
10	0	90 + 13.4	0	19.6

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.

On two of the five knives, a third tube was mounted, through which bailing twine was passed to mark the exact point of injection. This was used for later soil sampling. The treatments that included twine were nine and 10 (See Table I).

The studies were planted during the week of June 14 - 21, 1979. Seed used was a 90 day hybrid, SG-10, marketed by Farmland Industries. It was planted with a two row International Harvester planter, model 296, at nine kg/ha. The harvesting was performed with a model "A" Gleaner-Baldwin combine during the week of October 1 - 5. One cultivation was done on each of the sites on August 8 and 9.

Although weather data is not available, the Major County location remained quite droughty most of the summer, having received two rainfalls. The Roger Mills County site, however, did not experience drought stress, as 1979 was an unusually moist summer for that area.

Two weeks after planting, soil samples were collected to observe movement of P away from the point of injection, and to monitor the availability of P due to the presence of NH_4^+. The sampling was done by locating the twine that was placed with the fertilizer, and then taking soil samples in 2.5 cm increments away from the string vertically downward. An attempt was made to take samples horizontally away from the twine, but the planting operation (which caused considerable furrowing) had all but destroyed the placement of the soil in relation to the string.

Harvesting for yield was accomplished by threshing the middle two rows of each four row plot, collecting the grain and weighing it. A sample was drawn from each plot for moisture determination, so that all yields could be calculated on a dry weight basis or adjusted to 12 percent uniform moisture content.

Wheat Studies

Three wheat experiments were established in the fall of 1979. They all were located on a branch of the Agricultural Experiment Station, Oklahoma State University. The stations were 1) Eastern Research Station, Haskell, 2) Agronomy Research Station, Stillwater, and 3) Irrigation Research Station, Altus. The soil at the Haskell station is a Taloka silt loam (fine, mixed, thermic Mollic Albaqualfs), at Stillwater, a Kirkland silt loam (fine, mixed thermic Udertic Paleustolls), and at Altus a Hollister clay loam (fine, mixed, thermic Pachic Paleustolls).

A randomized complete block design was employed for the studies, with four replications and seven treatments at Haskell and Altus, and five treatments at Stillwater due to space limitations. The plots at Altus and Haskell were 15.2 m by 4.6 m, while at Stillwater they were 18.3 m by 4 m. Table II shows the specific treatments used in the experiments. Ammonium nitrate was used for the broadcast treatments of N, and APP was the source of P. NH_3 was the source of N for the knifed treatments.

The equipment used to apply the fertilizer is identical to that described in the sorghum section of this chapter, with the exception that a Barber Engineering Company plot fertilizer spreader was used to broadcast the ammonium nitrate. All plots were disked after

TABLE II

FERTILIZER TREATMENTS USED IN DUAL INJECTION STUDY ON WINTER WHEAT, 1979-1980

Treatment No.	kg/ha N Broadcast	kg/ha N Knifed	kg/ha P Broadcast	kg/ha P Knifed
*1	0	0	0	0
2	0	112	0	0
3	93 + 19	0	30	0
4	93	19	0	30
5	19	93	30	0
6	0	93 + 19	0	30
*7	0	93 + 19 plus 0.56 kg/ha nitrapyrin	0	30

*These not included at Stillwater.

treating to a depth of 10 cm.

A treatment utilizing 0.56 kg/ha active ingredient of nitrapyrin (2-chloro-6-(trichloromethyl)pyridine), a compound with a trade name of "N-Serve 24-E," marketed by Dow Chemical Company to inhibit nitrification in the soil, was incorporated in the wheat study. In was mixed with the APP and injected through the squeeze pump.

Bailing twine was also used in these experiments (except at Altus) to facilitate gathering of soil data in the same manner as before. At Stillwater, samples were drawn from treatments two, four, and six, and at Haskell from treatments six and seven.

The Altus and Haskell locations were planted with the variety TAM W-101, and Stillwater with Osage. They were all sowed with 33.6 kg/ha certified seed during the week of October 22 - 26, 1979, with a 25 cm spaced hoe type grain drill.

The only chemical treatment that any of them received occurred in Stillwater, where on April 7 they were sprayed with 0.28 kg/ha each of bromoxynil and MCPA, for control of wild buckwheat and mustards.

Forage samples were taken from all the wheat plots for N and P analysis as the plants began their active spring growth during the weeks of March 24 - 31. It was discovered at this time that two plots had been ruined by the installation of drainage tile at Altus, treatment six, replication one, and treatment one, replication three.

The experiments were harvested the last week of June, 1980, using the same combine having a three meter header as described in the sorghum section. The plots were threshed by cutting the middle three meters of each plot, the grain collected and weighed for yield, and a sample drawn for chemical analysis of N and P concentration.

Laboratory Data

The soil samples that were collected were all analyzed for N and P concentration. The soils were dried at 100 degrees C for 24 - 48 hours. The nitrogen determinations were done by the micro-Kjeldahl procedure, described by Bremner (1965). The P content of the soils was determined by the Bray No. 1 P extraction method (Oklahoma State University Agronomic Services, standard laboratory procedures).

The forage and grain samples were also analyzed for N and P concentration. The N was analyzed by performing a sulfuric acid digestion, followed by the micro-Kjeldahl method, and the P by a nitricperchloric digestion, followed by colorimetric determination of P content. Both 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 (SAS 72). 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 and P content of forage and grain. The comparisons of means was accomplished by using the protected least significant difference (LSD) procedure. This procedure implies that the "F" value for treatment effects must be significant before the means of the various treatments will be compared by the conventional

LSD procedure.

Missing data was handled by the procedure suggested by Snedecor et al. (1967).

CHAPTER IV

RESULTS AND DISCUSSION

Sorghum Studies

The grain sorghum yield results from the two locations in 1979 are reported in Table III. No differences were noted from any treatment at either location. The "F" values for treatments in the analysis of variance were not significant at the .05 level.

Yields from the Roger Mills County location were, in general, much higher than those from the Major County site. This was due primarily to the amount of moisture available for plant use, as mentioned in the previous chapter. At the Major County site, moisture was the limiting factor for plant growth, so fertilizer this season had little if any effect upon yield. It is interesting to note that there were no trends established due to fertilizer application, that the yields do not indicate any response whatever to the treatments. Any treatment differences are probably due as much to varying soil conditions and stand establishment as to anything that was done to increase yields. The soil test values (Agronomic Service Laboratory, Oklahoma State University Agronomy Department) show that the nitrogen was already adequate, with 59 kg NO_3^- - N per hectare, and P levels were 80 percent sufficient for grain sorghum production with a soil test index of 32. The pH value was 7.6.

TABLE III

YIELD DATA FROM DUAL INJECTION STUDY ON GRAIN SORGHUM, 1979

Treatment			Yield, kg/ha	
	kg/ha			
Method	N	P	Major Co.	Roger Mills Co.
1. Check	0	0	1313	3179
2. APP Broadcast	6.7	9.8	1780	3543
3. APP Injected	6.7	9.8	1653	3121
4. APP Broadcast	13.4	19.6	1749	3828
5. APP Injected	13.4	19.6	1446	3440
6. NH_3 Injected	90	0	1379	3099
7. NH_3 Injected, APP Broadcast	90 + 6.7	9.8	1506	2973
8. NH_3 Injected, APP Injected	90 + 6.7	9.8	1792	3394
9. NH_3 Injected, APP Broadcast	90 + 13.4	19.6	1574	3965
10. NH_3 Injected, APP Injected	90 + 13.4	19.6	1343	3835
			NSD (.05)	NSD (.05)

There is another mitigating factor that should be brought to light, and that pertains to the spacing of the dually injected material in relation to the row spacing of the crop. The NH_3 and APP were injected at 45 cm intervals, and the crop rows were 100 cm apart. With this spacing scheme, and the dry conditions that prevailed, it is entirely possible that the roots never intercepted much of the fertilizer, particularly phosphorus, since some of the injections may have occurred as far as 22 cm from the row. This fertilizer would surely be lost for plant use for that crop year. The soil data on the movement of fertilizer N and P bears out that little movement occurred away from the injection point (See Figures 1-4). Therefore, the amount of fertilizer the plants contacted and absorbed was probably lower than the rates applied.

The Roger Mills County location was not moisture deficient, so some other factor or factors must have been operative to give no statistical differences among treatments. The soil test values prior to fertilization indicate that very little nitrate nitrogen or phosphorus was available for plant use. The NO_3^- - N value was nine kg/ha, and the P index value of 16 means that soil P was about 50 percent sufficient for sorghum crop production. This should indicate that a substantial response to fertilizer would occur. There were no general trends established, however,

The yields from treatments two through five may lend some insight regarding the placement of APP and the plants ability to utilize the phosphorus. Treatments two and three compare broadcasting and disking in the P to injecting the APP, both at 9.8 kg/ha P. The average yield from the broadcast treatment (treatment two) was 3543 kg/ha, and for

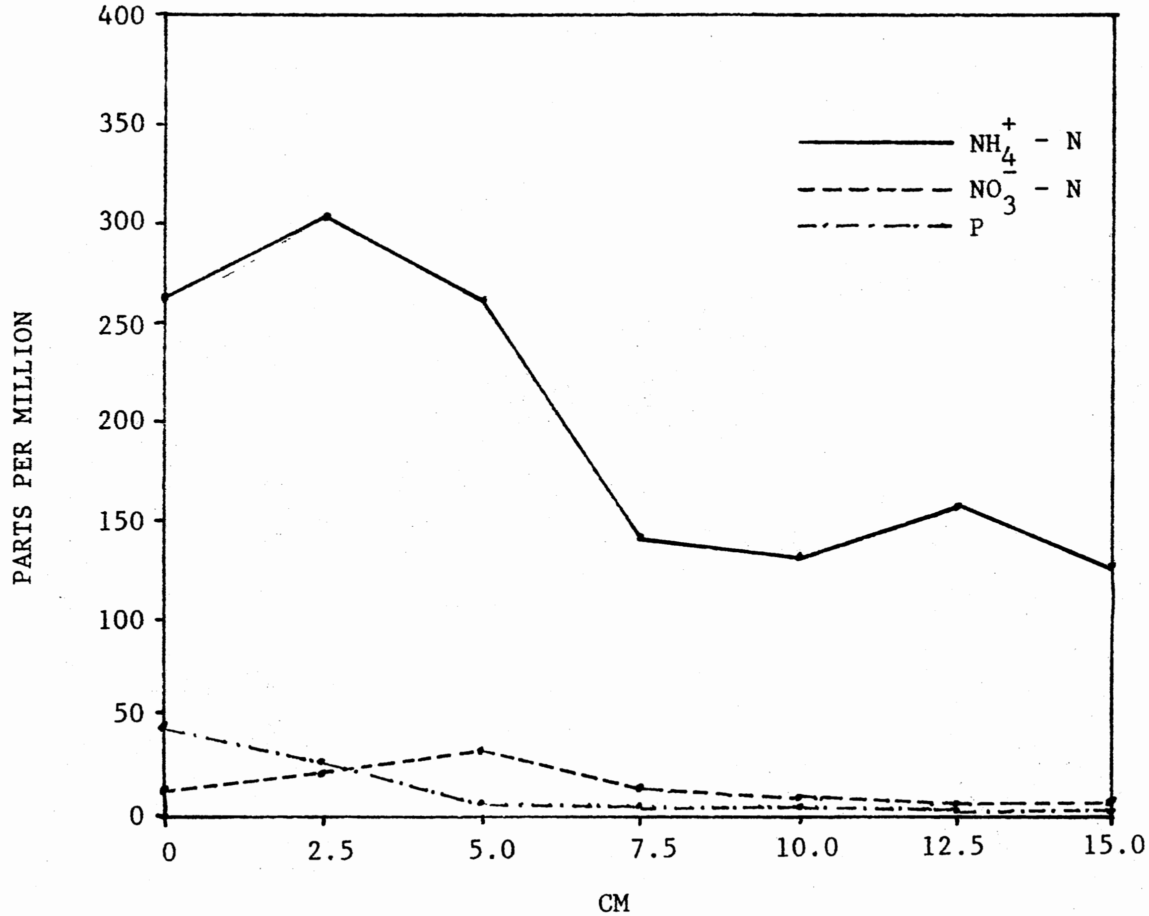

Figure 1. NH_4^+ - N, NO_3^- - N, and P in Soil Samples Taken in 2.5 cm Increments From Point of Injection; 90 kg N/ha as NH_3 and 9.8 kg P/ha as APP in Roger Mills County, 1979.

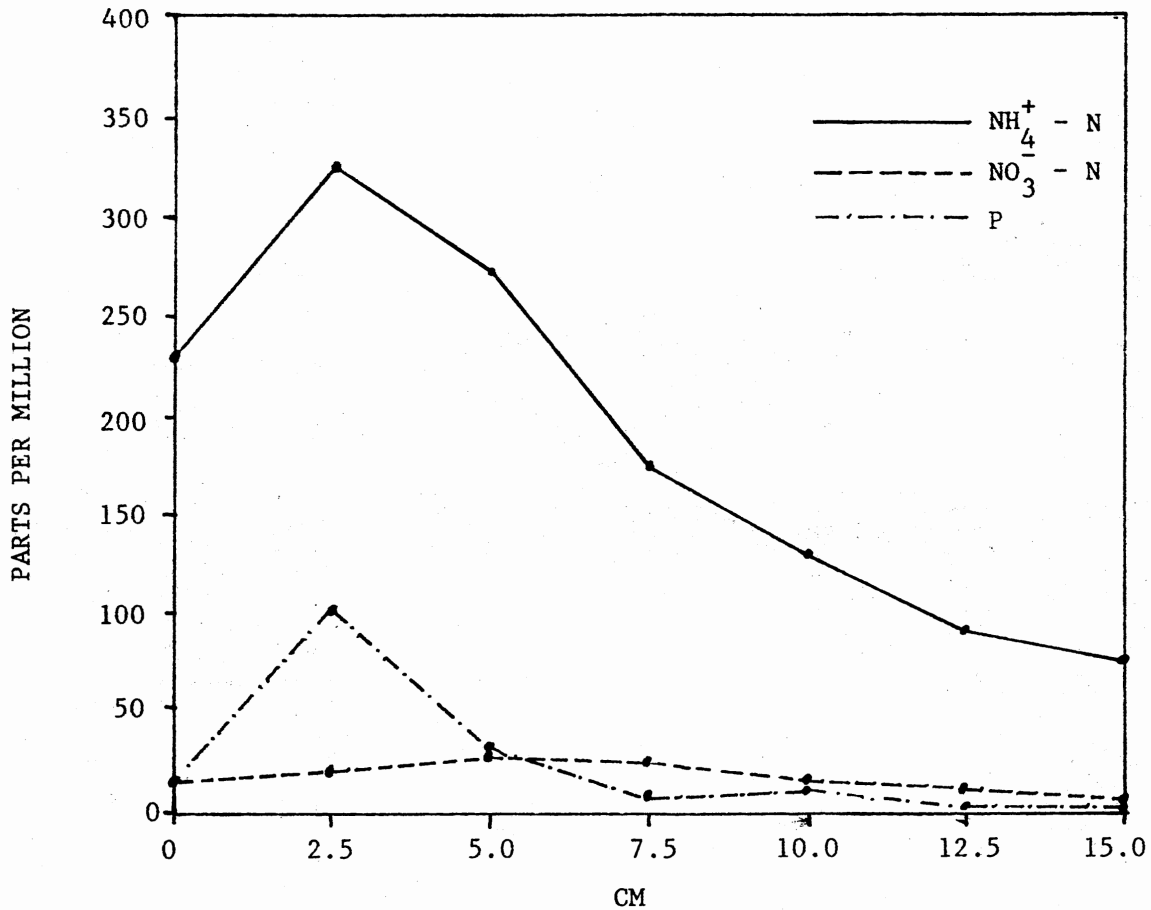

Figure 2. NH_4^+ - N, NO_3^- - N, and P in Soil Samples Taken in 2.5 cm Increments From Point of Injection; 90 kg N/ha as NH_3 and 19.6 kg P/ha as APP in Roger Mills County, 1979.

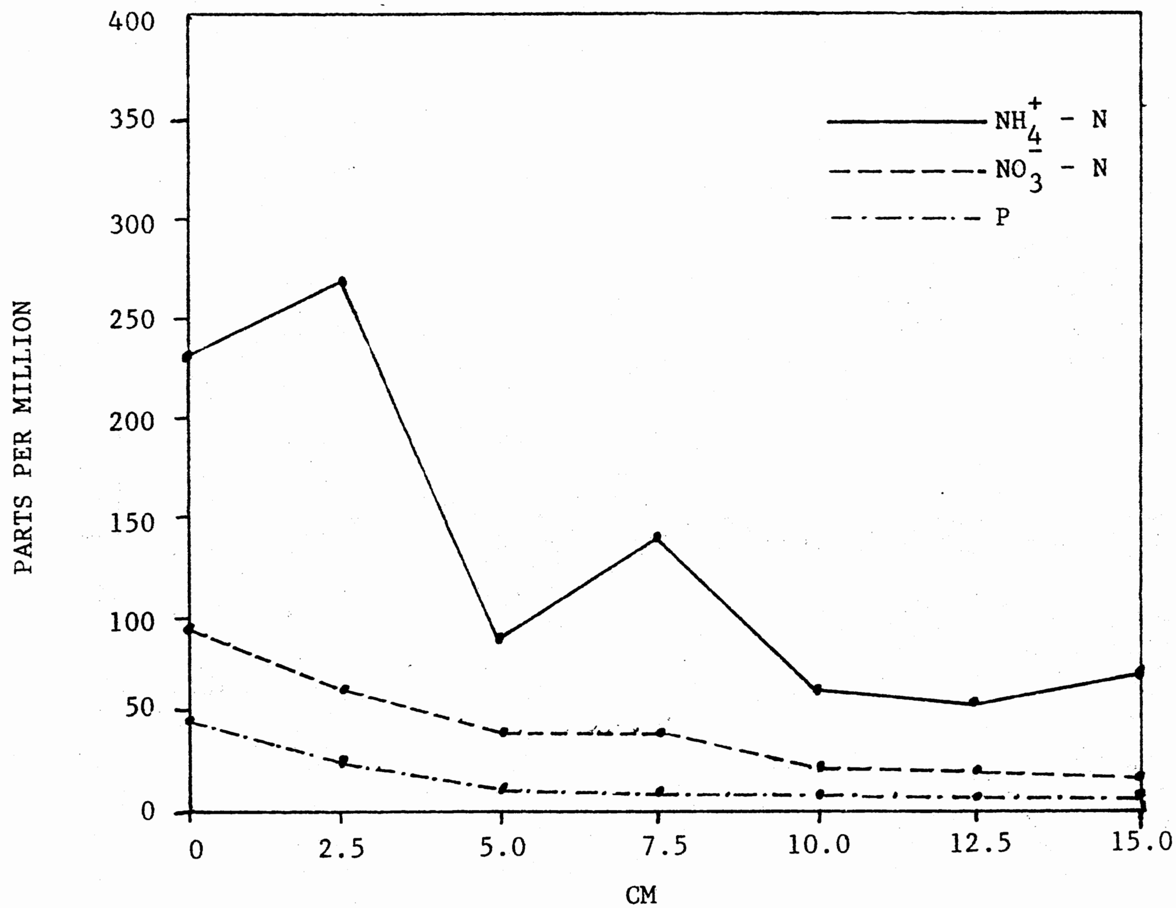

Figure 3. NH_4^+ - N, NO_3^- - N, and P in Soil Samples Taken in 2.5 cm Increments From Point of Injection; 90 kg N/ha as NH_3 and 9.8 kg P/ha as APP in Major County, 1979.

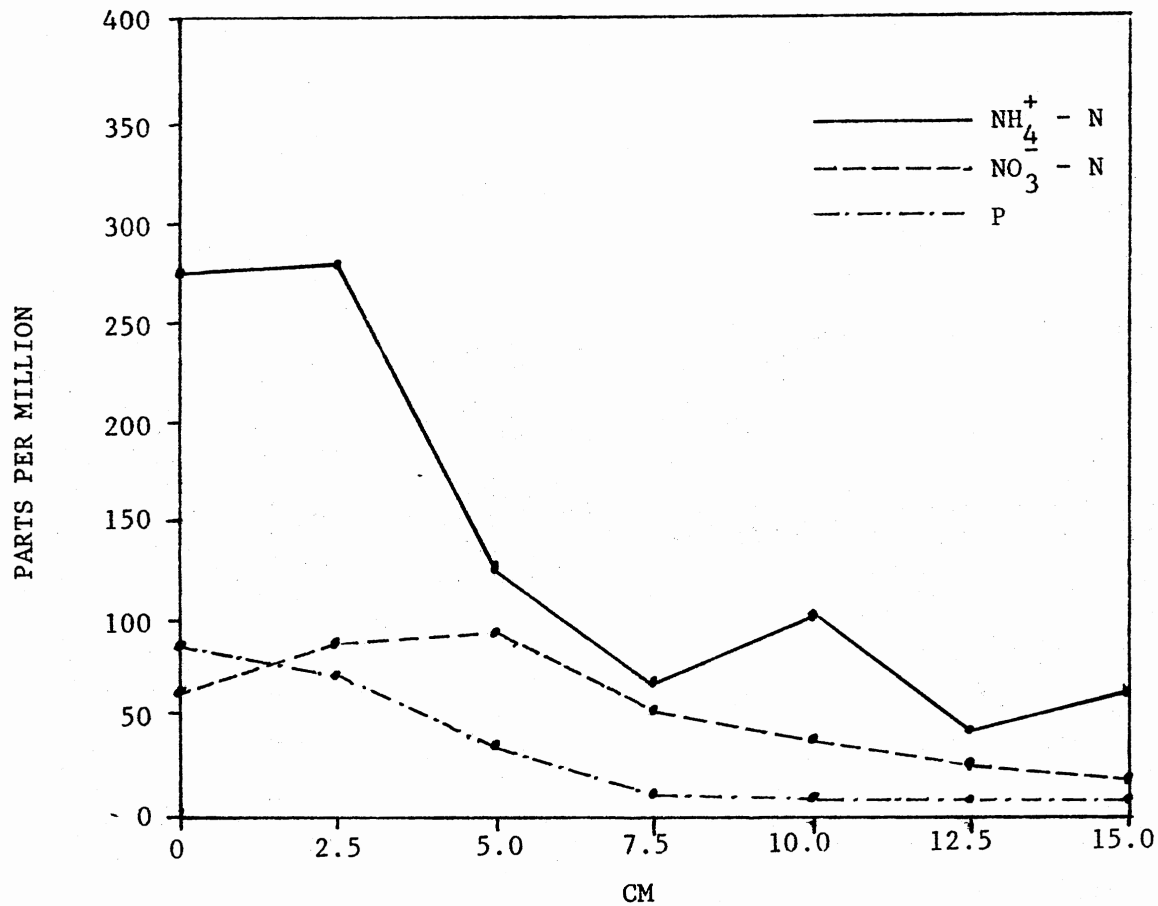

Figure 4. NH_4^+ - N, NO_3^- - N, and P in Soil Samples Taken in 2.5 cm Increments From Point of Injection; 90 kg N/ha as NH_3 and 19.6 kg P/ha as APP in Major County, 1979.

treatment three, 3121 kg/ha. Treatments four and five compare the same thing, but at 19.6 kg/ha P. Treatment four averaged 3828 kg/ha, and treatment five yielded 3440 kg/ha, it being the injection treatment. It has been proven that banding fertilizer phosphorus will give better responses than broadcasting the same amount of P, if the plant root is able to come in contact with the banded P (Tisdale and Nelson 1975). Although the differences are not significant, this may indicate that the plants did not intercept the P from the injected treatments. This may support the suggestion that 45 cm injection spacings are not conducive to fertilizer uptake where the rows are 100 cm apart.

Soil Analysis - Sorghum Study

Figures one through four are illustrations of the N and P content of the soil samples taken two weeks after the injections of NH_3 and APP. They show the movement of NH_4^+ - N, NO_3^- - N, and P away from the point of injection two weeks following fertilization. In all cases, the ammonium N seems to be greater 2.5 cm from the injection point than at any other point sampled. This is probably due to the pressure of the NH_3 as it leaves the injection tube, forcing downward into the soil, where it is then rapidly combined with water molecules to form NH_4^+ ion.

The nitrification process took place more rapidly at the Major County site than at the Roger Mills County site, judging by the amount of NO_3^- in the injection zone. Even though the initial amounts of nitrate were higher at Major County, it still appears that there were substantial amounts of nitrate near the injection (within 7.5 cm), whereas this was not the case at Roger Mills County.

These illustrations depict the fate of injected P at both locations. In all instances, no P moved any further than 7.5 cm from the injection point during a two week interval. It is probably safe to assume that not much more movement took place during the rest of the summer. This being the case, the plant roots would have had to intercept the P in order to utilize it since the phosphorus was not moving toward the plant (or anywhere else). If the injection was not close enough to the row for this to happen, then the fertilizer was wasted for that year.

The amounts of P found by soil analysis are consistent with amounts that were applied. The 19.8 kg rates show somewhat more P than the 9.8 kg rates. The amount of P did not affect the movement of the P in any treatment.

Wheat Studies

Unlike the sorghum studies, there were significant treatment differences recorded at all three locations for the wheat studies at the .05 level of probability. The yields at the Altus location were generally lower than those at the other two sites. This is due largely to the fact that precipitation during the months of February, March, and April was below normal, so that the wheat went through a period of drought stress, and was not able to realize its full potential since vegetative growth was stunted. Table IV gives the precipitation amounts for the growing season and the long term averages for that same period of time for all locations.

The yield data are displayed in Table V. At Stillwater, the highest yields came from treatments that included injected phosphorus. There was no difference between broadcasted ammonium nitrate with

TABLE IV

PRECIPITATION (CM) RECEIVED DURING WHEAT GROWING SEASON, 1979-1980

	Stillwater		Haskell		Altus	
Month	Season	Average	Season	Average	Season	Average
September	3.28	8.45	0.65	5.90	0.25	5.90
October	3.50	6.95	6.28	6.95	6.33	6.95
November	6.68	4.63	14.30	2.13	3.10	2.12
December	4.75	3.35	2.77	2.93	2.75	2.92
January	4.47	2.90	3.25	4.55	6.00	2.45
February	1.53	3.38	2.55	5.15	1.60	2.55
March	7.20	4.65	10.90	8.43	1.45	3.18
April	13.40	7.15	8.15	11.87	4.75	5.63
May	16.38	11.55	13.85	12.45	33.60	11.17
Totals	61.18	53.00	62.50	67.85	59.83	42.88

TABLE V

YIELD DATA FROM DUAL INJECTION STUDY ON WHEAT, 1979-1980

Treatment			Yield (kg/ha)		
	Rate (kg/ha)				
Method and Source	N	P	Stillwater	Haskell	Altus
Check	0	0	--	1883	1254
NH_3 Injected	112	0	1925	1595	1864
NH_4NO_3 Broadcast, APP Broadcast	93 + 19	30	2552	2314	1951
NH_4NO_3 Broadcast, APP Injected	93 + 19	30	3016	2860	2143
NH_3 Injected, APP Broadcast	93 + 19	30	2195	2800	1407
NH_3 Injected, APP Injected	93 + 19	30	3008	2905	1982
NH_3 Injected, APP Injected + "N-Serve" (0.56 kg/ha)	93 + 19	30	--	2778	1917
LSD (.05)			651	493	383

injected APP and dually injected anhydrous ammonia and APP. The lowest yield was obtained by injecting NH_3 with no P added. There was no zero fertilizer plot included at Stillwater. When both the ammonium nitrate and APP were broadcasted and disked in, the yield was not significantly higher than injecting NH_3 and broadcasting the APP. From the Stillwater data, it appears that injecting the APP, either dually with NH_3 or with broadcasted NH_4NO_3, results in the greatest yield. Injected NH_3 with broadcasted APP produced significantly lower yields than injecting the APP.

The N and P content of the forage samples taken from Stillwater are shown on Table VI. Inspecting the nitrogen content of the samples, it is shown that N percentages are analogous to yields obtained. The treatments that included injected P show a significantly higher N percentage than those where P was brodcasted or where no P was added. The very same observation obtains concerning the P content of the forage. The injected P treatments, either with broadcasted N or dually injected N and P, resulted in significantly higher P content of the forage than the other treatments in the study. There is also a trend concerning the treatments that included broadcasted P. The N and P content of the NH_3 treatment are somewhat lower than those of the NH_4NO_3 broadcast-disk-in-treatment. This corresponds with the yields obtained for the respective treatments.

Table VII shows the N and P content of grain samples taken at the time of harvest. Regarding the nitrogen content of the samples, the percent N in the dual injection treatment is significantly higher in all treatments except NH_3 without P. However, if the yield is taken into consideration, the total amount of N per hectare in the grain is

TABLE VI

N AND P CONTENT IN WHEAT FORAGE, STILLWATER, 1979-1980

Treatment	N, %	P, %
112 kg N/ha Injected	5.01	0.30
112 kg N/ha 30 kg P/ha, Both Broadcast	4.99	0.32
112 kg N/ha (NH_4NO_3), 30 kg P/ha, Injected	5.31	0.38
112 kg N/ha (NH_3), 30 kg P/ha, Broadcast	4.88	0.29
112 kg N/ha (NH_3), 30 kg P/ha, Dual Injection	5.30	0.37
LSD (.05)	0.24	0.04

TABLE VII

N AND P CONTENT IN WHEAT GRAIN, STILLWATER, 1979-1980

Treatment	N, %	P, %
112 kg N/ha (NH_3)	2.46	0.35
112 kg N/ha (NH_4NO_3), 30 kg P/ha Broadcast	2.14	0.37
112 kg N/ha (NH_4NO_3), 30 kg P/ha Injected	2.22	0.35
112 kg N/ha (NH_3), 30 kg P/ha Broadcast	1.99	0.31
112 kg N/ha (NH_3), 30 kg P/ha Dual Injection	2.53	0.41
LSD (.05)	0.22	0.05

far greater in the dual injection treatment than in the other treatments. The addition of P appears to have enhanced the plants ability to absorb nitrogen. The content of phosphorus in the grain is also significantly higher for the dual placement treatment than all others except the broadcast treatment of both N and P. Once again, if the yields of the various treatments are taken into account, the amount of P absorbed and translocated to the grain on a per hectare basis is greater when the fertilizer is dually injected than when applied otherwise. The N and P have a synergistic effect upon each other.

The Haskell site provided results that differed from the Stillwater data. The yields can be divided into two groups. The first three treatments (see Table V) are significantly lower in yield than the last four treatments. Within the first three treatments, there was a depression in yield when NH_3 was applied with no P. It is significantly lower than where both fertilizers were broadcasted. This soil, the Taloka silt loam, is rather low in native phosphorus, with a soil test index value of 15. This is about 30 percent sufficient for wheat production (Oklahoma State University Agronomic Service Laboratory). The plants were not able to utilize the N present because P was limiting.

The forage analysis in Table VIII shows that the greatest amount of P absorbed occurred with the dual placement treatment. It contained significantly more P than any other treatment. There was a marked drop in P content associated with the dual injection treatment plus nitrapyrin. Several other treatments contained more P in the plant tissue. The plants appear to have absorbed as much N as possible where no P was applied, and that it was diluted somewhat where P

TABLE VIII

N AND P CONTENT IN WHEAT FORAGE, HASKELL, 1979-1980

Treatment	N, %	p, T
Check	5.18	0.27
112 kg N/ha (NH_3)	5.15	0.28
112 kg N/ha (NH_4NO_3), 30 kg P/ha Broadcast	4.55	0.22
112 kg N/ha (NH_4NO_3), 30 kg P/ha Injected	4.81	0.29
112 kg N/ha (NH_3), 30 kg P/ha Broadcast	4.61	0.22
112 kg N/ha (NH_3), 30 kg P/ha Dual Injection	5.12	0.34
112 kg N/ha (NH_3), 30 kg P/ha Dual Injection Plus 56 kg/ha nitrapyrin	4.62	0.24
LSD (.05)	0.17	0.03

accompanied the N. No real trends seem to be established concerning the nitrogen content of the forage.

By the end of the growing season, the grain analyses, displayed on Table IX, show that those treatments that lagged far behind in forage P content had become equivalent to the dual injection treatment. There were no significant differences among the treatments regarding either nitrogen or phosphorus content in the grain. On a per hectare basis, the treatments that yielded the greater amount of grain also took up more P. There was no dilution of N or P in the grain. This may suggest that even though P was added, it still may have been a limiting factor for plant growth. The pH of this soil is 4.6, which contributes to soil sorption of phosphorus much more than if the pH was in the 5.5 - 7.0 range. Some of the fertilizer P may have been tied up during the growing season.

At the Altus location there was a significant response to applied nitrogen on all treatments with one aberration. Where NH_3 was injected and APP broadcasted, the yield did not differ significantly from the check plot. All other treatments showed a response to fertilization. There did not appear to be a response to the method in which the phosphate was applied, or to any phosphorus application at all. The NH_3 treatment alone gave a yield of 1864 kg/ha, which was not significantly lower than any treatment which received P, although it was somewhat less than those which had P included. The highest yield recorded was 2143 kg/ha, from the NH_4NO_3 broadcast - APP injected treatment. The dual injection treatment was somewhat lower, at 1982 kg/ha; the treatment that included nitrapyrin yielded 1917 kg/ha.

As previously mentioned, the wheat experienced drought stress in

TABLE IX

N AND P CONTENT IN WHEAT GRAIN, HASKELL, 1979-1980

Treatment	N, %	P,%
Check	2.55	0.27
112 kg N/ha (NH_3)	2.37	0.25
112 kg N/ha (NH_4NO_3), 30 kg P/ha Broadcast	2.45	0.29
112 kg N/ha (NH_4NO_3), 30 kg P/ha Injected	2.43	0.27
112 kg N/ha (NH_3), 30 kg P/ha Broadcast	2.50	0.27
112 kg N/ha (NH_3), 30 kg P/ha Dual Injection	2.49	0.28
112 kg N/ha (NH_3), 30 kg P/ha Dual Injection plus 0.56 kg/ha nitrapyrin	2.75	0.29
No Significant Differences (.05)		

the spring, which may have contributed to poor responses to P fertilization. However, the site already contained fairly high P levels prior to fertilizer application. The soil test results showed 85 percent sufficiency. This may also have contributed to the zero response observed with P applications.

Looking at the N and P content in wheat forage from Altus on Table X, there was significantly more N in all treatments over the check plot. Within those treatments that received nitrogen, the treatment with NH_3 and broadcast APP was lower in nitrogen content than the dual placement treatment or the NH_3 only treatment. This corresponds well with the yields obtained. Data on grain N and P content is not available from Altus.

Soil Analysis - Wheat Study

Soil samples were drawn from the Stillwater plots two weeks following fertilization as described in Chapter III. They follow much the same trend as those from the sorghum study. Figures 5 - 7 depict the results from the sampling procedure. The NH_3 only treatment shows that at the point of injection, the NH_4^+ - N content is very high, after which it drops off sharply at 5.0 cm away from the point of injection. Apparently, there was some nitrification occurring during this period, because the NO_3^- - N levels are higher near the injection point, after which they decline and level off 7.5 cm from the point. The NH_4^+ does not seem to have affected the availability of soil P; there is very little if any gradient of P moving away from the injection point. This may indicate that if the presence of NH_4^+ does affect the availability of P to the plant, perhaps the P must already be in a form that

TABLE X

*N AND P CONTENT IN WHEAT FORAGE, ALTUS, 1979-80

Treatment	N,%	P,%
Check	3.18	0.46
112 kg N/ha (NH_3)	4.32	0.44
112 kg N/ha (NH_4NO_3), 30 kg P/ha Broadcast	3.86	0.45
112 kg N/ha (NH_4NO_3), 30 kg P/ha Injected	3.63	0.47
112 kg N/ha (NH_3), 30 kg P/ha Broadcast	3.47	0.50
112 kg N/ha (NH_3), 30 kg P/ha Dual Injection	4.50	0.42
112 kg N/ha (NH_3), 30 kg P/ha Dual Injection Plus 0.56 kg/ha nitrapyrin	4.40	0.44
LSD (.05)	0.44	No Significant Differences

*Grain data not available.

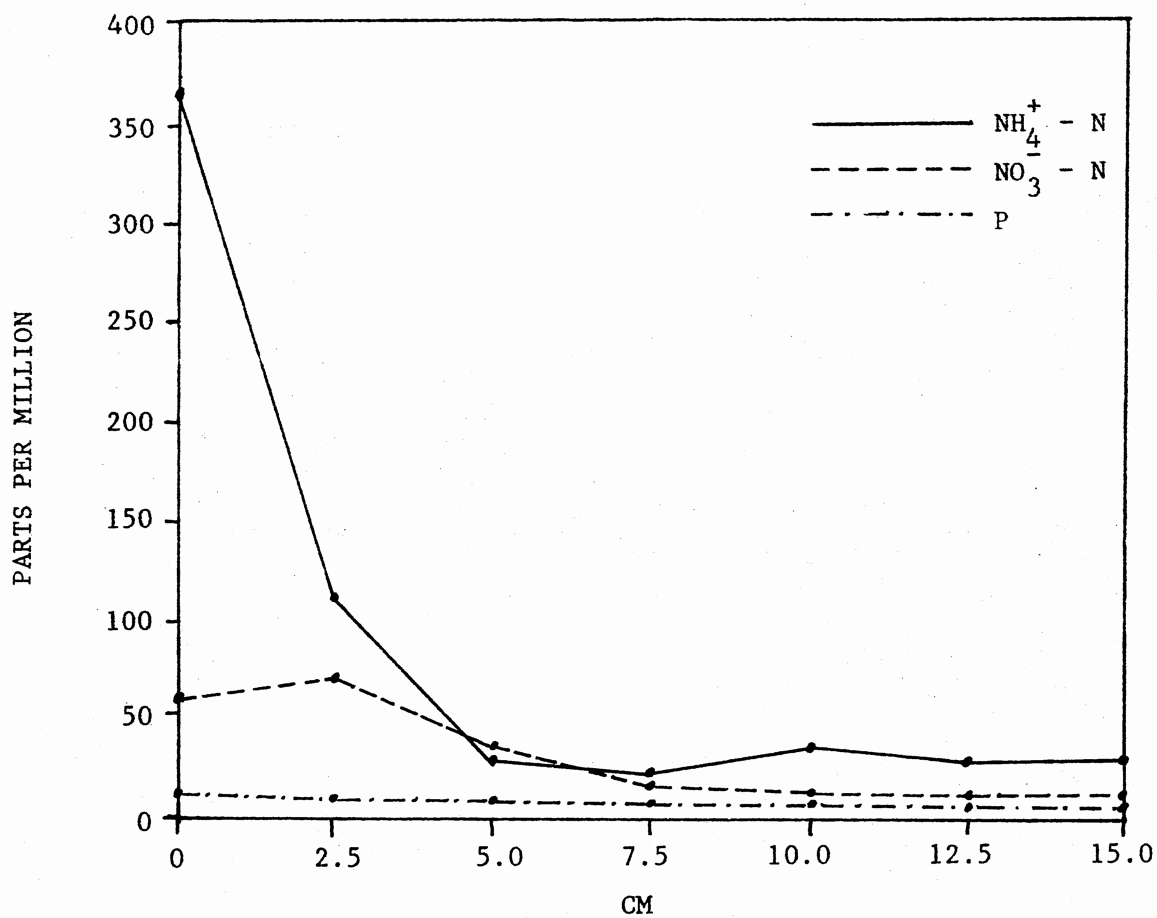

Figure 5. NH_4^+ - N, NO_3^- - N, and P in Soil Samples Taken in 2.5 cm Increments From Point of Injection; 112 kg N/ha as NH_3 and 0 kg P/ha, Stillwater, 1979-1980.

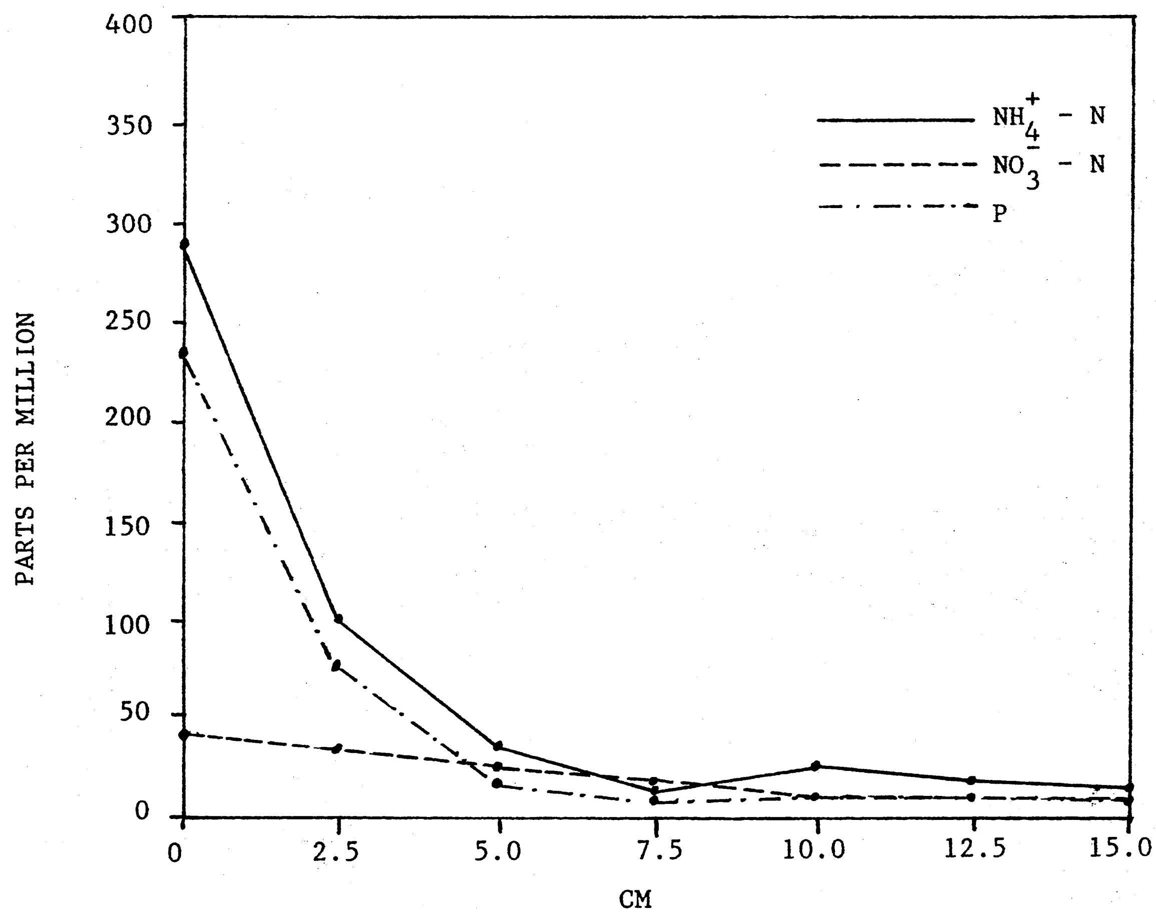

Figure 6. NH_4^+ - N, NO_3^- - N, and P in Soil Samples Taken in 2.5 cm Increments From Point of Injection; 93 kg N/ha as NH_4NO_3 Broadcast, and 30 kg P/ha as APP Injected, Stillwater, 1979-1980.

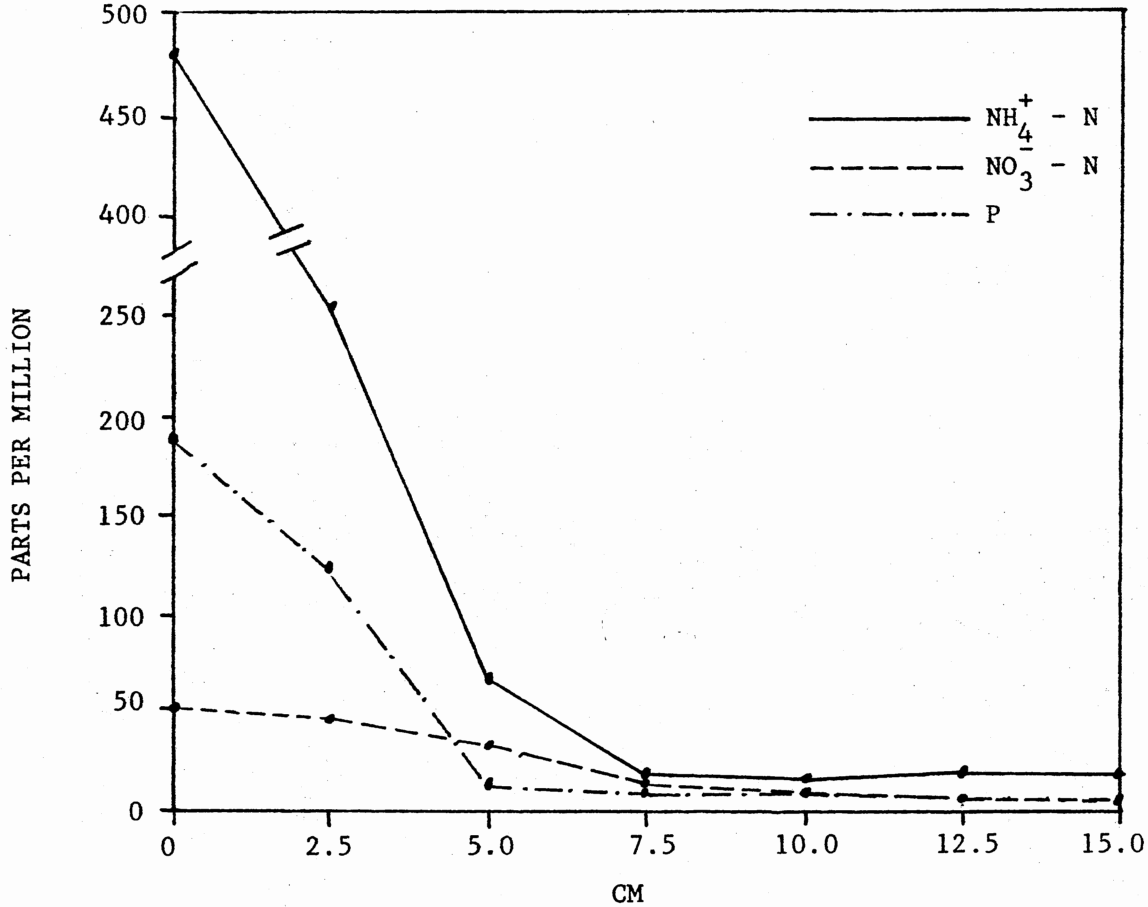

Figure 7. NH_4^+ - N, NO_3^- - N, and P in Soil Samples Taken in 2.5 cm Increments From Point of Injection; 93 kg N/ha as NH_3 and 30 kg P/ha as APP, Stillwater, 1979-1980.

is readily useable to the plant.

Treatment four, where N was broadcasted and P injected, also shows a high content of NH_4^+ near the injection point, although not as high as the previously discussed treatment. This is due in large part to the ammonium that constitutes part of the APP fertilizer. There was also some nitrification occurring in the injection zone, as Figure 6 indicates. The phosphorus moved very little after is was applied. According to the soil analysis, there were 238 ppm at the injection point, and only 21 ppm 5.0 cm away.

Treatment six, which is the dual injection treatment, is illustrated in Figure 7. The same results pertaining to the nitrification of NH_4^+ are evident in this treatment as seen for treatments two and four. The ammonium content also goes from a very high level (481 ppm) to 18 ppm within 7.5 cm of the point of injection. The soil content of Bray No. 1 extractable P does not appear to be any greater where N was injected with the P than where P was injected alone, nor did it move any further from the injection point. It must be remembered, however, that these samples were taken only two weeks following injection. In order to determine if the ammonium affected the availability of the P it would be necessary to monitor the band throughout the entire growing period. That was not within the scope of this study.

Figures 8 and 9 are the results of soil samples taken at Haskell in the same manner as before. The two treatments observed were the dual injection plots and the dual injection plus N-serve plots. The amounts of ammonium in the first 7.5 cm of the injection zone are far greater than observed in the Stillwater soil. In both illustrations, the NH_4^+ levels are in the 700 ppm range. There was some nitrification

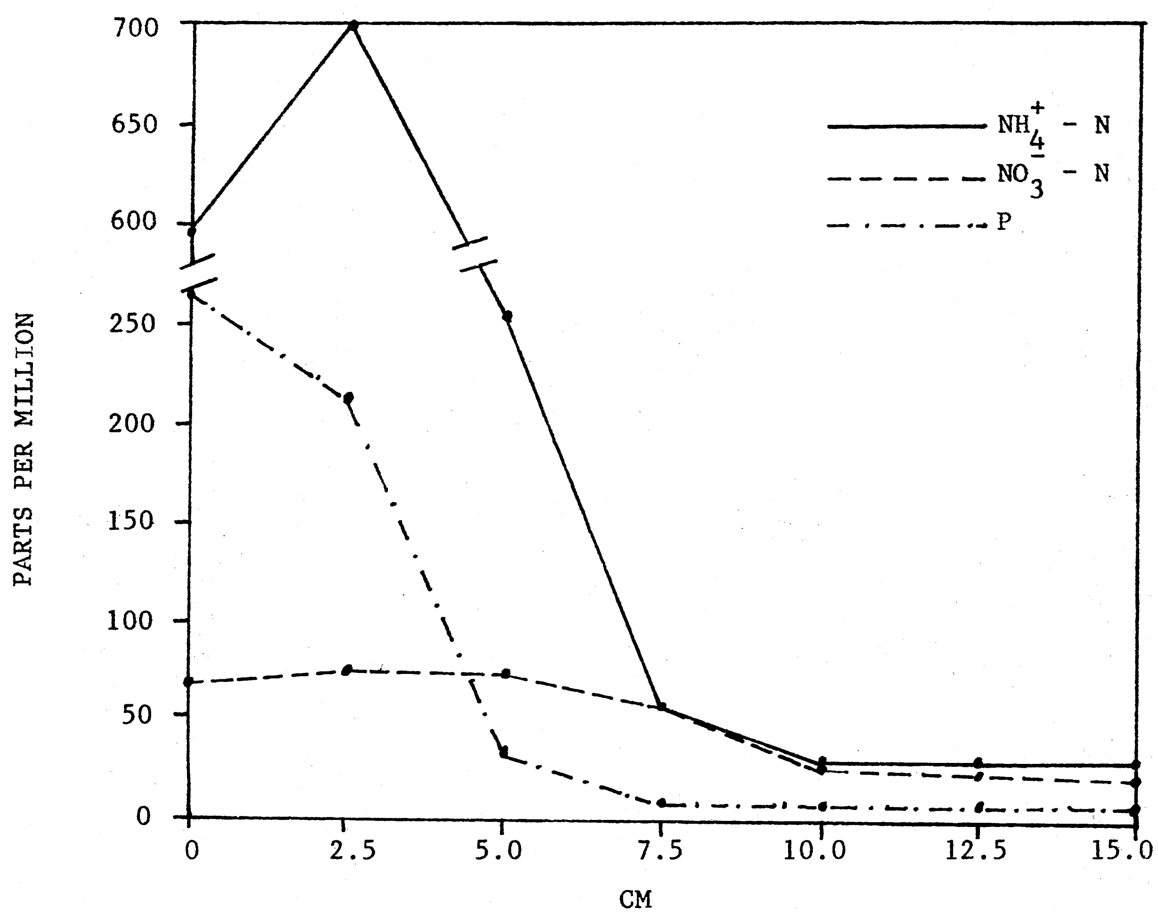

Figure 8. NH_4^+ - N, NO_3^- - N, and P in Soil Samples Taken in 2.5 cm Increments From Point of Injection; 93 kg N/ha as NH_3 and 30 kg P/ha as APP, Dually Injected, Haskell, 1979-1980.

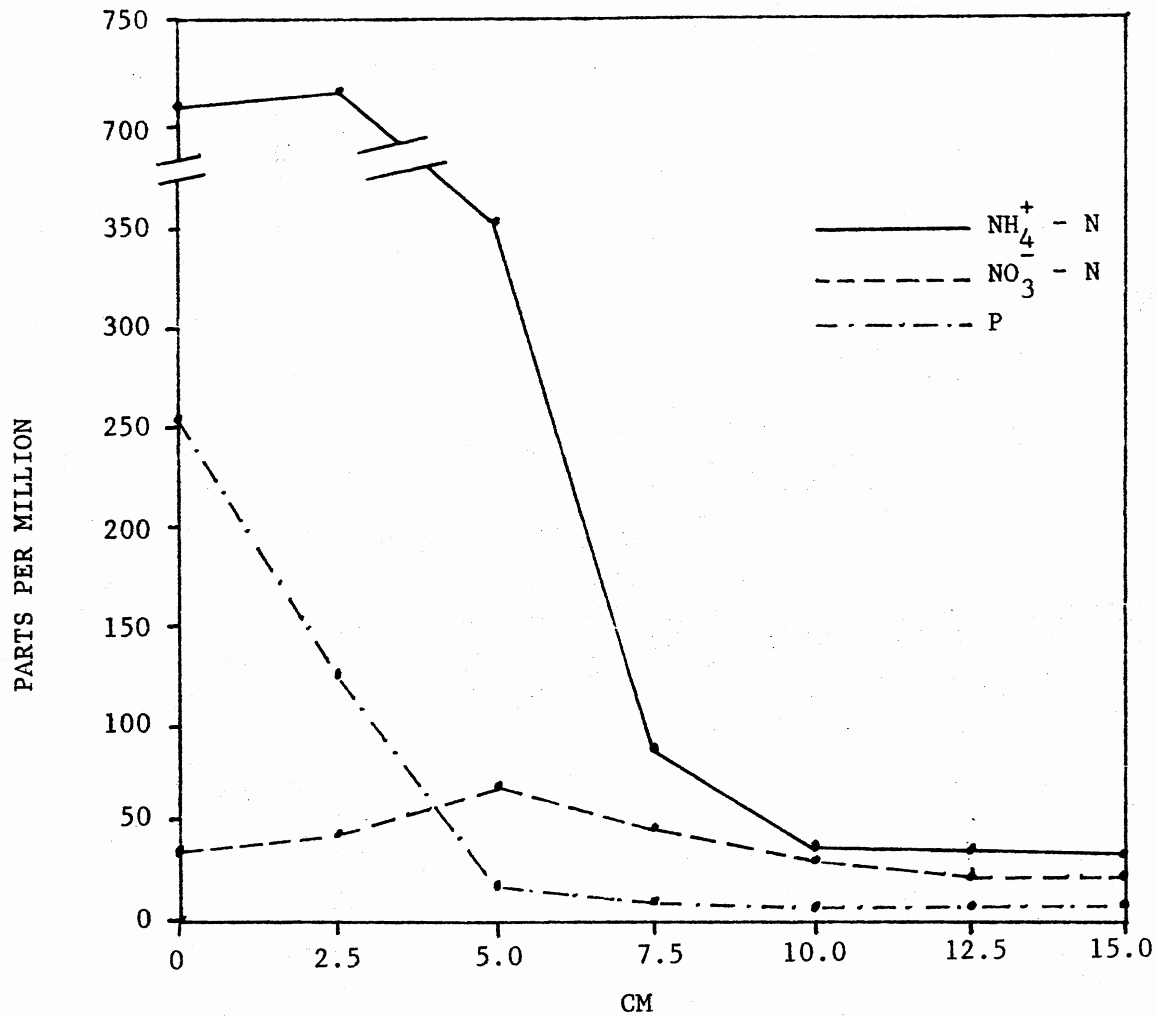

Figure 9. NH_4^+ - N, NO_3^- - N, and P in Soil Samples Taken in 2.5 cm Increments From Point of Injection; 93 kg N/ha as NH_3, 30 kg P/ha as APP, and 0.56 kg/ha "N-Serve," Haskell, 1979-1980.

occurring in the injection zone; within the first 7.5 to 10.0 cm there is appreciably more nitrate than further away from the injection point. It appears that the nitrification was inhibited somewhat by the addition of N-serve within the first 5.0 cm (see Figure 9), but then at 7.5 cm the nitrate levels rise to 64 ppm, after which they fall off again. The amounts of P found were very similar for the two treatments, with the typical sharp dropoff occurring within the first 5.0 to 7.5 cm. Pre-fertilization levels of P were rather low, about seven ppm. Nitrate levels were in the range of 30 ppm before applications.

No soil data are available for the Altus location.

CHAPTER V

SUMMARY AND CONCLUSIONS

Studies on two crops were devised to test the effectiveness of dual injection of anhydrous ammonia and ammonium polyphosphate (APP, 10-15-0) compared to more conventional means of fertilizer application. In the summer of 1979 two sorghum studies were conducted in western Oklahoma, testing dual injection against broadcasting N and P at two rates of phosphorus. The sole test to determine fertilizer method efficiency was yield determination. Extensive soil sampling of the injection zone was also performed to monitor movement of fertilizer away from the injection point.

A follow-up study was conducted on winter wheat during the growing season of 1979 - 1980 at three locations across Oklahoma to test the method of dual injection. Only one rate of phosphorus was used, and nitrapyrin, a nitrification inhibitor, was also tested. Soil samples of the injection zone were taken at two of the three locations. During early spring growth, forage samples were taken to analyze the N and P content. Grain samples at harvest were also drawn for N and P analysis, and yield determinations were made.

The following conclusions have been reached from the sorghum and wheat studies.

Sorghum Study

No significant differences at the .05 level of probability for yield were found for the various treatments at either location of the sorghum experiments. One of the problems encountered was the lack of sufficient rainfall, making comparisons due to fertilizer application very difficult. Sufficient evidence was obtained to state that the placement of the injected fertilizer adversely affected the outcome of the experiment. The 45 cm spacings used in conjunction with 100 cm row spacing did not enable the plants to make full use of the fertilizer that was applied.

The soil sampling that was performed helped to bear out this conclusion. The movement of fertilizer nitrogen and phosphorus did not exceed 7.5 cm two weeks following fertilizer injection. The all but negligible movement of the fertilizer shows that unless the injection band is placed where the roots can come into contact with it, it will do no good. Random placement of injected or banded fertilizer where wide row spacing is practiced is questionable.

Wheat Study

Statistical analysis of the yield data showed significant treatment differences at all locations at the .05 level. In all cases, where the APP was injected, either alone or with NH_3, the highest yields were obtained. There was not a significant increase in yield where dual injection was used over injecting the APP and broadcasting ammonium nitrate. Both of these injected P treatments were significantly higher in yield than the broadcast N and P treatment, except at

Altus, where the soil P levels were already quite high. The most dramatic increase with injected P occurred at Stillwater, where the soil P levels were intermediate among the locations. At Haskell, there was a depression in yield with application of NH_3 without P over the check treatment.

The application of nitrapyrin with dual injection did not significantly change the yield over dual injection alone.

The forage and grain analysis showed that where soil P was low, the dual injection method augmented the content of P in the forage over other methods. Where soil P was more adequate, either method of injecting P gave higher P content in forage. In the case of high soil P, any method of P application gave statistically equivalent amounts of P in the forage. All of the effects discussed for forage are less evident in the grain content of P, where few treatment differences were found. The exception to this occurred at Stillwater, where the dual injection treatment gave significantly higher P levels in the grain over all treatments except the P injected, N broadcast method.

The soil test data reveals that little movement of P took place whether injected alone or with NH_3. Dual injection of N and P did not seem to enhance the solubility of P over injecting it alone, nor did it affect the movement of P. Nitrapyrin did seem to inhibit the nitrification process two weeks after application, but beyond this the effects are not known.

Suggestions for Further Research

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

Further field work also needs to be conducted along the same lines as this study, to determine effects of dual injection over a long period of time. It would be enlightening to try this method of fertilization on a row crop such as sorghum or corn utilizing a different spacing scheme than was employed for this study. The author feels that dual injection of N and P has possibilities in certain cases, and should not be overlooked as an efficient means of increasing our agricultural production.

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