EFFECTS OF TIME OF NITROGEN APPLICATION ON WHEAT AND NITROGEN APPLICATION RATES ON GRAIN SORGHUM FOR A WHEAT-GRAIN SORGHUM DOUBLE-CROPPING SYSTEM UNDER DRYLAND CONDITIONS

By

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PREFACE

This study concerns the effects of time and rate of nitrogen applications in a wheat-grain sorghum double-cropping system. The major objective was to determine the best time of nitrogen application to wheat and the optimal rate of nitrogen application to grain sorghum. The effects of nitrogen application rates on soil pH and nitrate accumulation in the soil profile were also studied. This study was conducted over a three year period (1978-1981) at the Eastern Research Station near Haskell, Oklahoma.

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CHAPTER I

INTRODUCTION

Double cropping is becoming more popular because it uses land and other resources more efficiently and can produce bigger net profits. However, it also has its problems. Weed competition is usually higher in double cropping systems than in monocropping systems and, in Oklahoma, water is often lacking at critical times for crop production. In a double cropping system each crop may affect the performance of the other crop. For example, nitrogen (N) applications to grain sorghum may leave residual N in the soil that can either aid or hinder the performance of a succeeding wheat crop. Sorghum residue may inhibit the germination and growth of the wheat crop and wheat straw may hinder sorghum establishment.

The purpose of this experiment was to investigate the effects of different N application rates to sorghum (from 0 to 202 kg/ha) and different times of N applications to wheat (fall, spring, or half fall and half spring) on wheat and grain sorghum yields. The effects of these treatments on soil pH and soil nitrate nitrogen (NO_3^--N) accumulation were also studied.

CHAPTER II

REVIEW OF LITERATURE

Double-cropping, the growing of two successive crops on the same land in one year, has been shown to be profitable under favorable climatic conditions and proper management. Double-cropping makes better use of climatic resources (35, 106) and reduces production costs while increasing net income and land use efficiency (55). Having a crop continually established also helps control erosion (102). Camper et al. (27) reported that soybeans, sorghum, and maize, double-cropped after barley, were profitable in Virginia if the double-crop was planted early and if nitrogen (N) was applied when barley straw was turned into the soil. Rupp (105) had moderately good yields of wheat and soybeans in a double-cropping system when adequate soil moisture was available, but Malcom (68) found lack of sufficient water drastically decreased yields of soybeans double-cropped after wheat grain removal. Swearingin (115) reported double-cropping was successful in Indiana when moisture was adequate, but over several years 20% of the double-crops failed because of moisture shortages. In Texas, under irrigation, good yields of sorghum double-cropped after wheat were obtained (6).

Martin et al. (69) state that sorghum usually produces well after small grains and is more drought resistant than are many crops, making it a good double-crop choice; however, sorghum often retards growth and reduces yields of crops planted after harvesting sorghum.

Double-cropping resulted in more total grain production in a two-year study by Crabtree and Rupp (35) in Eastern Oklahoma, but grain production of the individual crops was usually reduced. Part of the reason for yield reduction of individual crops was that late harvesting of the first crop often delayed planting of the second crop past the optimal planting date. When compared to wheat planted near the optimal planting date, late planted wheat has lower grain yields because it extracts less water from the soil, develops a less extensive root system, tillers less, produces fewer heads, accumulates less dry weight before winter (which can reduce winter survival rates) and uses N less effectively (41, 46, 47, 60, 64, 119). Alhagi (5) indicated that increasing wheat seeding rate may compensate for late planting. Grain sorghum yields varied little with date of planting in Australia in a study by Millington et al. (81), but Heatherly et al. (54) reported that grain sorghum yields were reduced if crops were planted earlier or later than mid-May in Tennessee. Martin et al. (69) reported better control of chinch bugs and sorghum midge with early plantings.

Weed control in double-cropping systems is more difficult than in monocropping systems (105). One reason for this is that herbicides with longer residual effects that can be used to effectively control weeds in one crop may also reduce the growth of the subsequent crop and, therefore, are not suitable for double-cropping (101).

Tillage Methods

No-till and minimum tillage lend themselves well to double-cropping systems because of the short time usually allowed for tillage between successive crops. Allen et al. (6) reported no-till required only one fifth the time conventional tillage required. Numerous studies give several comparisons between no-till and minimum tillage vs. conventional tillage methods. Residues and stubble left on the field with no-till and minimum tillage reduce wind and water erosion, protect soil structure from the damaging effects of raindrop impact, prevent soil crust formation, and increase soil water storage because of increased infiltration and reduced runoff and evaporation (5, 6, 13, 14, 15, 16, 28, 37, 50, 51, 74, 79, 99, 102, 107, 115, 125, 126). Increased soil water storage under the stubble usually increases crop yields but may be a problem on poorly drained soils (113). Crops grown no-till generally use more available soil moisture during their life cycles and use it more efficiently than do crops grown with conventional tillage practices (16, 99, 107).

Increased soil water content and shading of the soil by the stubble and residue reduce soil temperatures (13, 14, 15, 51, 124). Low soil temperatures can cause problems for crops that need high spring temperatures for germination and establishment (113), but reduction of spring soil temperatures is not a problem for late planted crops (124). Allen et al. (6) reported no-till plots yielded better than did conventional tillage plots because the wheat residues protected the sorghum seedlings from scorching temperatures. Black and Siddoway (13) postulated that low soil temperatures decreased mineralization of urea fertilizers.

One of the problems that sometimes occurs with no-till and minimum tillage systems, especially with double-cropping, is that the residues of the previous crop adversely affect the subsequent crop. When large amounts of residue are present at planting, wheat and other plants are often chlorotic, spindly, stunted, and generally weak (92, 126).

Researchers have attributed these conditions to N immobilization (62, 69), phytotoxins produced by microorganisms (31, 73), phytotoxins released directly from live plants (19), and phytotoxins released from plants as a by-product of decomposition (53, 92). Stunting and yellowing of plants occur most frequently when residues are present under wet, cool conditions (71, 89, 90, 122), but can occur under dry conditions as well (61). Low pH is more conducive to stunting and yellowing of plants if residues are present (90).

Nitrogen applications were used to overcome some of the stunting problems, especially if residues were mixed with the soil (69). Kimber (62) found that addition of N overcame low tillering and low wheat yield caused by mixing straw with the soil, but did not overcome the inhibition of germination caused by the straw. Many researchers found that N applications did not help overcome stunting and yellowing of plants, especially if residues were left on the surface of the soil, and concluded that phytotoxins produced as plants decompose were responsible for the chlorotic and stunted response of plants (42, 62, 72, 74, 92, 126).

Decaying residues help improve soil structure and increase aggregate stability, soil organic matter content, soil N content, and availability of most plant nutrients (13, 14, 37, 85). Residues also provide food and shelter for insects and diseases harmful to crops (51) and may produce phytotoxins which can predispose plants to diseases (9, 91, 100, 120).

No-till and minimum tillage reduce machine, fuel and labor costs (5, 37, 50, 51, 115, 126) but usually increase herbicide costs (50). Graffis et al. (51) list additional and special equipment costs as disadvantages to no-tillage systems but Malcom (68) showed a slightly modified drill planter could be used in no-till planting to reduce costs.

It is generally reported that weed control is more of a problem in no-till and minimum tillage systems than in conventional tillage systems (14, 37, 51, 72, 106, 123). Perennial weeds cause the most problems in no-till systems, but glyphosate |N-(phosphonomethyl)glycine| shows promise for controlling them (126). Bipyradilium herbicides can also be effective in controlling weeds in no-till systems (104). Black and Siddoway (13) reported decreased weed populations under no-till as compared to conventional tillage because the stubble shaded the ground.

Graffis et al. (51), Unger (123), and Unger et al. (126) reported poor seedbed preparation and stand establishment under no-till and minimum tillage. Allen et al. (6) overcame this problem with a fluted coulter in front of the planting unit.

Cannel and Finney (28) and Stranak (114) observed that the strength and bulk density of soils increased and porosity decreased under no-till practices, but Black and Siddoway (14) reported that bulk density decreased as the amount of residues increased. High bulk density can be either an advantage or a disadvantage, depending on the crop being grown. Soane and Pidgeon (113) observed that large root crops such as beets and carrots may have a significantly reduced yield if grown in soils of high bulk density. However, in experiments by Stranak (114), cereal grains produced most when bulk density was highest.

In other research, no-till and minimum tillage reduced soil compaction (37, 51, 113), resulted in more earthworms in the soil (28), decreased exchangeable calcium, apparently because of microbial immobilization of calcium (14), and caused lime and fertilizers to accumulate near the soil surface (51).

One of the most important comparisons between no-till and minimum tillage vs. conventional tillage is the difference in crop yields. Many doing work in tillage management practices show that yields with no-till are about as good or better than with conventional tillage if important factors such as weeds, seedbed preparation and toxins can be controlled (5, 6, 13, 14, 16, 50, 74, 75, 84, 94, 99, 106, 107, 114, 123, 125, 126). However, if these factors are not controlled, yields may be reduced significantly. Consistently poorer yields with no-till were reported by Davidson and Santelmann (37).

Nitrogen Application to Grain Sorghum

Grain sorghum usually responds readily to applied N, especially under favorable moisture conditions (34). Both recommended N application rate and crop response to applied N vary with management practices, yield goals, and water and nutrient availability (34, 112). Soil test correlation research shows that N application to grain sorghum should be based upon yield goals. Rates as high as 256 kg/ha are recommended under the most favorable climatic conditions in Oklahoma. Correspondingly lower rates are recommended as yield goals and water sufficiency decrease. Management practices such as minimum tillage often return large amounts of residues to the soil just before planting and usually necessitate extra N to overcome a N-immobilization produced N deficiency (14, 49). Failure to apply additional N reduces plant vigor, N uptake by plants and crop yield (27, 49, 59). Myers (83) showed sorghum produced top yields with only 22 kg applied N/ha in a dry year but in subsequent years with more available moisture the top yields for grain sorghum were obtained with applications of 150 to 200 kg N/ha. Martin et al. (69) state little yield increase resulted from applying N during dry years. Crop response to applied N is greater in soils with low initial N fertility than in soils with high initial N fertility (40).

The rate of applied N affects sorghum plants in more than just grain and fodder yield. High rates of N result in increased N uptake by sorghum plants, which usually increases protein content of sorghum forage and grain (29, 83). However, high N uptake by sorghum can also increase the amount of lodging, which in turn reduces both yield and test weight (65, 69). High N uptake also increases the quantity of prussic acid in sorghum, which toxin can be dangerous to animals feeding on the sorghum and may also reduce yields and performance of crops grown after sorghum (22, 69).

High N application rates also affect other production parameters. At high rates of applied N weed seeds absorb more N (43). When germinated these seeds produce more vegetative growth and have a longer flowering period than do seeds grown at lower rates of applied N. On the other hand, Fawcett and Slife (43) reported that seeds from common lambsquarter grown at high N rates have shorter dormancy, last less time in the soil and are, therefore, easier to control. Filimonov and Rudelev (45) reported that higher N application rates increased mineralization and use of immobilized N. Excess applied N will also lower soil pH more rapidly (1).

Nitrogen applied in excess of crop demand either remains in the soil for use by subsequent crops, or is lost to the environment through leaching, denitrification and immobilization (80, 98). The amount and depth of leaching depends on the soil, the amount of water applied, the use of N by the crop, the N source, and the method of N application. On a loam soil in Canada, Campbell and Paul (26) found that most of the N leached to only 30 to 60 cm. Olson et al. (87) reported most of the N applied during the fall was still in the top 10 cm of the soil profile the next spring on a silt loam in Kansas, while on a silt loam in Washington, Cochran et al. (33) found N accumulated at a depth of from 60 to 120 cm unless precipitation was high, in which case N was leached to lower depths. On fine sandy loams in North Dakota, Power et al. (98) found that most of the N leached to a depth of 150 to 250 cm, but Bauder and Montgomery (10) reported that the predominate depth of leaching was 80 to 115 cm, with some N leaching as deep as 180 cm. Examination of the interaction between N application rate, applied water, and leaching losses by Tanjo et al. (116) showed N began to accumulate in the soil (accumulation being the N remaining after crop use and leaching losses) at a N application rate of about 180 kg/ha with water application equivalent to 1/3 of evapotranspiration, at a N application rate of about 200 kg/ha with water application equal to evapotranspiration, and at a N application rate of 358 kg/ha with water application equivalent to 5/3 of evapotranspiration. Smika and Watts (112) reported that on a fine sand, N loss increased as the amount of applied water increased, with a water application equal to evapotranspiration leaching N below 150 cm. In a general survey of farms in southcentral Canada, Miller (80) reported up to 150 kg N/ha could be applied without large leaching losses if that was the amount of N recommended as based on potential crop use. However, only 110 kg N/ha caused large losses of N in the drainage water when 85 kg N/ha was the recommended amount. Smika and Watts (112) reported that N as ammonium nitrate (NH_4NO_3) applied broadcast to a fine sand in Nebraska was almost completely lost from the top 150 cm of soil, while a liquid NH_4NO_3-urea mixture injected into the irrigation system resulted in only a 50% loss of applied N. In experiments by Power et al. (98), more N was recovered by plants when applied as NH_4NO_3 than when applied as ammonium sulfate $|(NH_4)_2SO_4|$, calcium nitrite $|Ca(NO_3)_2|$, or urea. They also reported less leaching loss from NH_4NO_3 than from $Ca(NO_3)_2$ or urea.

Nitrogen can also be lost by denitrification. Denitrification usually takes place in parts of the soil profile that are under water saturated conditions. The N released diffuses to the surface of the soil and is lost to the atmosphere (7). Craswell and Martin (36) reported denitrification occurs when soils are above 90% water saturated, with one week of 100% water saturated conditions producing a loss of 55-60% of the applied N. Nitrogen loss by denitrification in a well drained fine sandy loam soil was reported by Carter et al. (29). Ganry et al. (49) reported that increasing the amount of wheat straw residue mixed into the soil increased denitrification. This was probably due to the increased carbon available to the denitrifying bacteria.

Jansson (57) reported N loss from denitrification was small compared to the amount of N immobilized by the soil and thus made unavailable to crop plants. A clay soil, with a small amount of added rice straw, can immobilize 20 mg N/100 g soil (approximately 500 kg N/ha) when kept at 30^oC for three months (59). A Houston black clay alone can immobilize 53-73 kg N/ha (63).

Effects of Residual Soil Nitrogen on Wheat

Most of the leached N accumulates within the rooting depths of wheat sorghum (30, 58). Fertilizer N that remains in the root zone as residual from excess N applications to previous crops can be used by subsequent crops to help satisfy their N requirements (2, 3, 109). The higher the amount of N applied to a crop, the less residual N is used by that crop (23, 26). If insufficient amounts of N are applied to the subsequent crop, the residual N can increase yields when soil moisture is adequate (33, 110, 117), reduce the incidence of yellow berry (103), increase tiller efficiency (live tillers/total tillers), and increase the number of tillers per plant (56). Increased availability of N usually results in a higher protein content of the grain (40, 69, 96, 108, 118). However, Campbell and Davidson (24) reported that wheat protein content was more dependent on temperature and moisture stress than on the amount of available N. Evapotranspiration, extraction of water from the soil, and water use efficiency also increase as N supply to the plant increases (2, 4, 23, 24, 111). High N levels generally result in greater plant dry weight accumulation and winter hardiness (47). However, Freyman and Kaldy (48) reported that although dry matter accumulation was greater at high N levels if sufficient P was present, an increase in N without sufficient P decreased winter hardiness of wheat.

Detrimental effects may occur if applied plus residual N provide excess N to the subsequent crop. Excess N causes lodging, and reduces yield (66, 69, 93, 103). High amounts of N may also delay maturity (69), reduce baking quality (11, 96), and inhibit root growth of wheat (23). Wells (128) found that a high N supply did not help wheat outgrow weeds, but produced greater weed growth.

If crops do not use the residual N, it usually becomes unavailable after one to two years due to immobilization, leaching and/or denitrification (57, 98). Filimonov and Rudelev (45) reported that large amounts of residual N were recovered the first year but in the second year very little N was recovered by plants. Power et al. (98) reported that N applied as NH_4NO_3 produced greater residual N effects than did N applied as ammonium sulfate, calcium nitrate or urea. Calcium nitrate had greater leaching losses and urea had greater leaching and volatilization losses than did NH_4NO_3. No explanation was given why NH_4NO_3 had slightly better residual N effects than did ammonium sulfate.

Effects of Time of Nitrogen Application on Wheat

Wheat response to N depends partially on the availability of N at or before critical growth stages. Power and Alessi (97) reported that final grain yields of spring wheat were closely correlated with the N content of the plant at the tillering stage. Nitrogen uptake at anthesis also increases wheat yield (23). Black and Siddoway (13) found that N applied early, before or soon after initial spring growth and definitely before the end of tillering, gave the best yields, but found no differences in protein content of the grain as a result of early or late N applications. High plant uptake of N during the forage and boot stages results in high protein content in the grain and straw at maturity (69, 118). In an irrigated Durum wheat field in the Imperial Valley in California, where yellow berry of wheat is a problem, uptake of N in the boot stage of growth gave the greatest decrease of yellow berry and the highest increase in protein content of the grain (103). Nitrogen uptake by wheat continues until the plant nears maturity; then most of the N absorbed by the wheat throughout its life span, and some N absorbed near maturity, moves into the grain (88). Metivier (78) reported that early N applications produced a greater dry matter yield than did late N applications.

The frequency of N applications necessary to supply wheat with N when needed most was studied by several researchers. Alessi and Power (2, 3) on a silt loam in North Dakota, showed greater yields, less N loss and greater N efficiency from annual N applications than from applications every two or six years. With three years data on a fine sand in Florida, Blue and Graetz (17) found no significant differences in yields between 1, 2, 4, 8 and 16 N applications per year unless untimely rains leached the applied N from the soil before the plants could absorb it (which happened one out of three years). Filimonov and Rudelev (45) reported no significant yield differences between one N application per year and two or more N applications per year.

The season of the year that N is applied can also affect yield and performance of wheat. Khalifa et al. (60) reported increased wheat yield when N was applied in the fall, but Boswell et al. (20) using 28 kg N/ha and Knapp and Knapp (64) using 22 kg N/ha found very little effect on wheat yield and performance from fall N applications. From their work on a fine sandy loam soil in North Dakota, Bauder and Montgomery (10) recommended that fall applications of NO_3^--N not be used if the expected winter precipitation was more than 10.7 cm. Cochran et al. (33) reported that fall applied N was leached to a lower part of the soil profile and did not increase yields unless nutrients were unavailable from the upper part of the soil profile because of drought. If N was available in the upper part of the soil profile, fall applied N was absorbed later by the plant and increased protein content of the wheat. A fall N application does not help winter survival, and it may even cause wheat to be more susceptible to winter kill if sufficient P is not available to plants (96). No differences in wheat yields or N losses between fall and spring applied N were found by Olson et al. (87), but Elder and Tucker (41), working on a Taloka silt loam soil near Muskogee, Oklahoma, showed that spring N applications increased yield considerably more than did fall N applications. Martin et al. (69) state spring N application is better, but fall N application is helpful if considerable residue with a high C:N ratio is present. Welch et al. (127) reported that both N use efficiency and wheat yields were greater for spring than for fall N applications. Doll (39) reported that wheat yields increased as the percent of the total applied N that was applied in the spring increased. A split application of N (part in the fall and part in the spring) was suggested as a possible alternative to spring application, especially if soils are very low in N (20, 127). Dmitrenko et al. (38) found that split applications gave higher yields in Russia than did fall applications during normal years but that in drier years no difference in yield between the two treatments was observed.

CHAPTER III

MATERIALS AND METHODS

A wheat-grain sorghum double-cropping field experiment was conducted at the Eastern Research Station near Haskell, Oklahoma from June 1978 to June 1981 on a Taloka silt loam soil (Mollic Albaqualfs) with 1-2% slope. The Taloka soil series is described by Gray and Galloway (52) as follows:

> Grayish-brown medium acid silt loam to 12 to 15" (30 to 48 cm) over light brownish gray silt loam to 18 to 20" (46 to 51 cm) over very pale brown silt loam with concretions to 26" (66 cm). Dark grayish brown medium acid blocky clay to 32 to 34" (81 to 86 cm) distinctly mottled with reddish and yellowish browns below and grading to grayer more mottled clays below 40" (102 cm). Very slow subsoil permeability; droughty; low fertility (p. 59).

The experiment was laid out in June 1978 on a field planted to Osage wheat the preceding October. A split plot in strips experimental design with four replications was used with 6.1 X 42.7-m N rate to grain sorghum treatment plots stripped across 13.7 X 42.7-m time of N application to wheat treatment plots. The intersection of the main treatment plots formed a subplot that was 6.1 X 13.7 m (including borders).

Wheat grain yields were obtained by harvesting a 3.0 X 12.2 m section from the center of each subplot using an Allis Chalmers Gleaner Model A mechanical harvester on 15 June 1978, 26 June 1979, 25 June 1980 and 24 June 1981. Stubble was left 15 to 30 cm high and wheat straw was scattered uniformly over the field.

Soil samples from the surface 15 cm were taken for each subplot on 15 June 1978 and 26 June 1979. On 28 November 1979 and 18 December 1980 each subplot was sampled with a soil probe (one probe per subplot) to a depth of 75 cm in 15 cm increments. Four additional soil probes to a depth of 120 cm in 15 cm increments were taken on 18 December 1980 (one probe per replication from the plot receiving the 202 kg/ha N to sorghum treatment). Surface soil samples (0-15 cm) were analyzed in the Oklahoma State University soil testing laboratory for nitrate nitrogen (NO_3-N), phosphorus (P), potassium (K) and pH. Soil samples from below the 15 cm depth were analyzed for NO_3-N only.

On 16 June 1978, 27 June 1979 and 26 June 1980, N as NH_4NO_3, was applied broadcast to the N rate to sorghum treatment plots at rates of 0, 34, 67, 101, 135, 168 and 202 kg/ha. On these dates P, as triple super phosphate, and K, as muriate of potash, were also applied broadcast at rates of 67.3 and 89.7 kg/ha, respectively, over the entire experimental area. These P and K rates provided 100% nutrient sufficiency levels of P and K as determined by the Oklahoma State University soil testing laboratory procedures and recommendations. Following fertilizer applications, 'Acco BR-Y93' grain sorghum was planted in 51-cm rows at a rate of 148,000 viable seeds/ha with an Allis Chalmers no-till planter equipped with fluted coulters 5 cm wide, double disk openers with 3.8-cm depth bands, and press wheels. Immediately after planting grain sorghum in 1978 and 1980, glyphosate |N-(phosphonomethyl) glycine| and terbutryn |2-(tert-butylamino)-4-(ethylamino)-6-(methylthio)-s-triazine| and in 1979, linuron |3-3,4-(dichlorphenyl)-1-methoxy-1-methylurea| and paraquat |1,1'-dimethyl'4,4' bipyridinium (ion as dicloride salts)| were broadcast on the experimental area as a tank mix preemergence application at rates of 1.7, 3.4, 0.6 and 1.1 kg/ha active ingredient, respectively, in 234 liters/ha water.

In July 1979 the grain sorghum received an application of ethyl parathion (0,0-diethyl 0-p-nitraphenyl phosphorothisate) at 0.6 kg/ha for control of chinch bugs, which gave excellent control.

Grain sorghum yields were obtained on 13 November 1979 by harvesting four 12.2-m rows from the center of each subplot with an Allis Chalmers Gleaner model A mechanical harvester. Grain sorghum was not harvested in 1978 and 1980 because of crop failure due to drought. The field was tandem disked twice each fall and planted to 'Osage' winter wheat on 10 November 1978, and to TAM W-101 winter wheat on 20 November 1979 and 12 November 1980 at a rate of 135 kg/ha. A total of 90 kg/ha N as NH_4NO_3 was applied broadcast to each time of N to wheat treatment plot either all in the fall (29 November 1978, 28 November 1979, and 18 December 1980), all in the spring (9 March 1979, 28 February 1980, and 26 February 1981), or half in the fall and half in the spring. The spring applications were made before jointing stage.

CHAPTER IV

RESULTS AND DISCUSSION

Before presenting the results of the experiment some of the assumptions and problems of this experiment will be reviewed. Because a crop responds to the total N available and not to the amount of N applied, a recommended procedure for applying N to crops is to sample the top 60 cm of soil to determine the amount of NO_3^--N available and make N applications to bring the soil N level up to the desired treatment level. This method was not used because the N application had to be made within a day of the wheat harvest for best use of available moisture and growing period, leaving insufficient time to test the soil and apply N accordingly. The N treatment rates given are the amounts applied and not the total N available to the crops. Since residual N from previous years varied depending upon previous fertilizer treatments, weather patterns and crop use, the actual available N varied from year to year for the same treatment. However, residual N effects were primarily a function of the amount of applied N and will be assigned to the treatment effects.

During the course of this experiment there was a year with average rainfall, a year with above average rainfall, and a year with below average rainfall, in that order. Not only were there differences in total rainfall but also differences in rainfall patterns (Figure 1). The weather conditions during the experiment applied their own treatments to

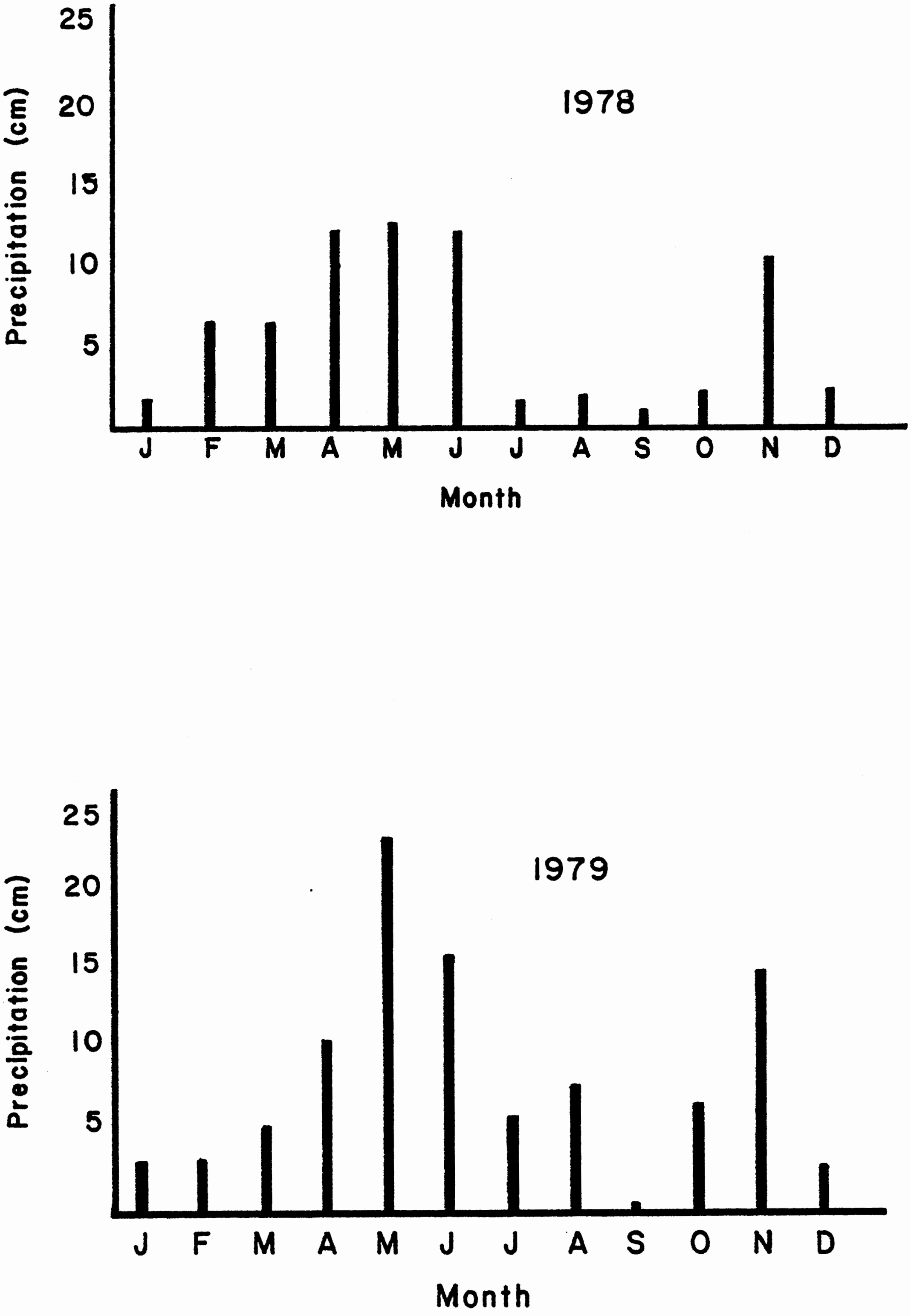
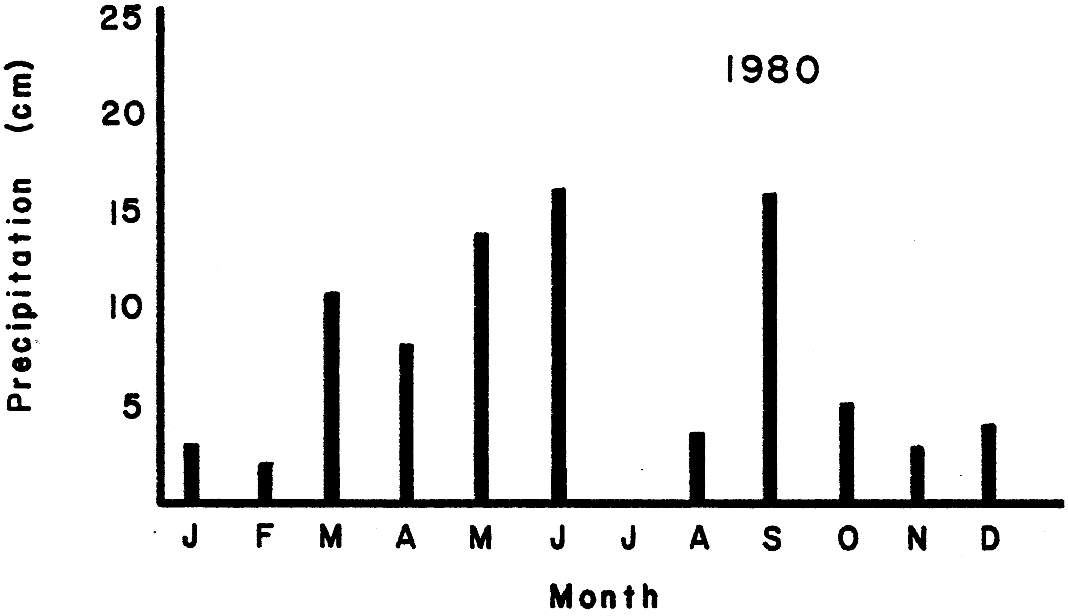


Figure 1. Monthly Precipitation During the Experimental Period



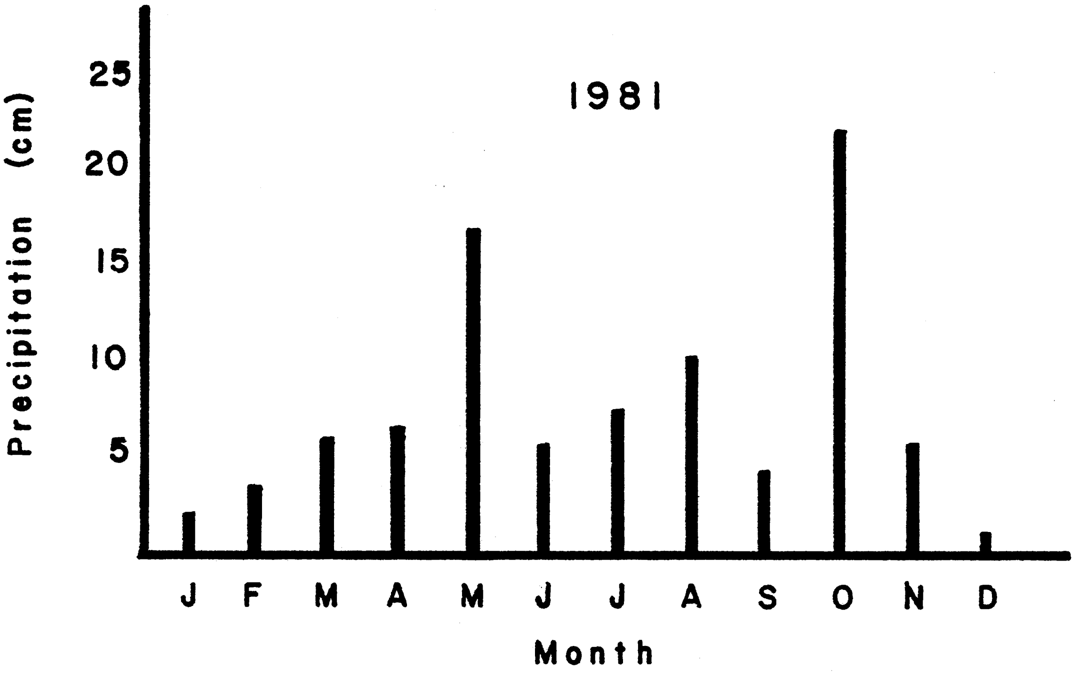


Figure 1. (Continued)

the experiment in addition to all other treatments applied. For example, in a dry year there would probably be less crop use of N (especially if crop failure resulted from the drought - which happened two out of three years with sorghum), less denitrification, and less loss of N through leaching. This would enhance the residual effects of the N application treatments. The interpretations given apply to the weather patterns experienced during these three years and care must be taken in extending these interpretations to other years and other weather patterns.

This experiment was laid out on a previously terraced field where the terraces had been removed but their effect was still partially evident. This caused unequal water distribution over the field and some variation in the soil, which resulted in large variations in data values among plots.

Wheat Yields

Effect of Time of N Applications to Wheat

The fall N application to wheat treatment produced higher yields every year than either split or spring N applications (Table I), but only in 1979 were the differences in yields statistically significant (OSL = .065, Table III, Appendix). Analyzing the combined three years' data showed that time of N application to wheat treatments produced no significant statistical differences in wheat yields |Observed significance level (OSL) = .126, Table VI, Appendix|. However, the fall N application produced the highest yield each year and the highest three year average yield on each rate of N application to sorghum treatment level. The spring N application always produced the lowest average yields for these same comparisons.

TABLE I

EFFECT OF TIME OF N APPLICATION TO WHEAT ON WHEAT YIELDS

Time of nitrogen application	1979	1980	1981	3 year average
Fall	2653a*	2281	1033	1989
Split (½ Fall - ½ Spring)	2427b	2212	867	1835
Spring	2341b	2098	718	1719
$LSD_{.10}$	210	167	300	373
$LSD_{.05}$	264	210	378	470

Values given are treatment means in kg/ha.
*Values not followed by the same letter are significantly different at the .10 level. The F tests performed on the data showed no significant differences at the .05 level for 1979 yields and no significant differences at the .10 level for 1980 and 1981 yields.

Sorghum residues disked into the soil shortly before planting wheat probably immobilized most of the available N, leaving wheat plants with little N for early growth. The fall N application produced the highest yields possibly because it replenished the wheat's N supply during early growth. Since rainfall was not excessive during the winter, little leaching occurred and plants receiving a fall N application had a good

N supply throughout their lifespan whereas plants receiving N in the spring probably suffered from N deficiencies during the fall and early winter.

Effect of N Application Rate to Sorghum

Wheat yields in 1979 did not respond significantly to residual N from sorghum N applications (Table III, Appendix). Nitrogen immobilization by sorghum residues probably made most of the residual N unavailable to the wheat in the fall and early spring. High NO_3^--N soil test values and lodging of the wheat in late spring on plots receiving high N applications to sorghum indicated some N had mineralized but did so too late to increase wheat yields. High rainfall in May and June probably contributed to wheat lodging. Except for May and June, the growing season had slightly below average rainfall. With this amount of moisture the 90 kg/ha N applied directly to the wheat was probably enough to satisfy the wheat's requirements and any additional N would not have increased wheat yield but may have increased wheat protein content as in experiments by Terman (118).

Differences in wheat yields between N rate to sorghum treatments were significant in 1980 (OSL = .065, Table IV, Appendix) with yield increasing as N rate to sorghum increased (Figure 2). Soil tests in the fall of 1979 indicated some residual NO_3^--N was present at planting and mineralization throughout the growing season probably supplied additional N to the wheat. Rainfall during the 1979-1980 growing season was above average and highest of the three year experimental period. Since water was not so limiting a factor as in other years the wheat was able to use more N than the 90 kg/ha applied to the wheat. It should be

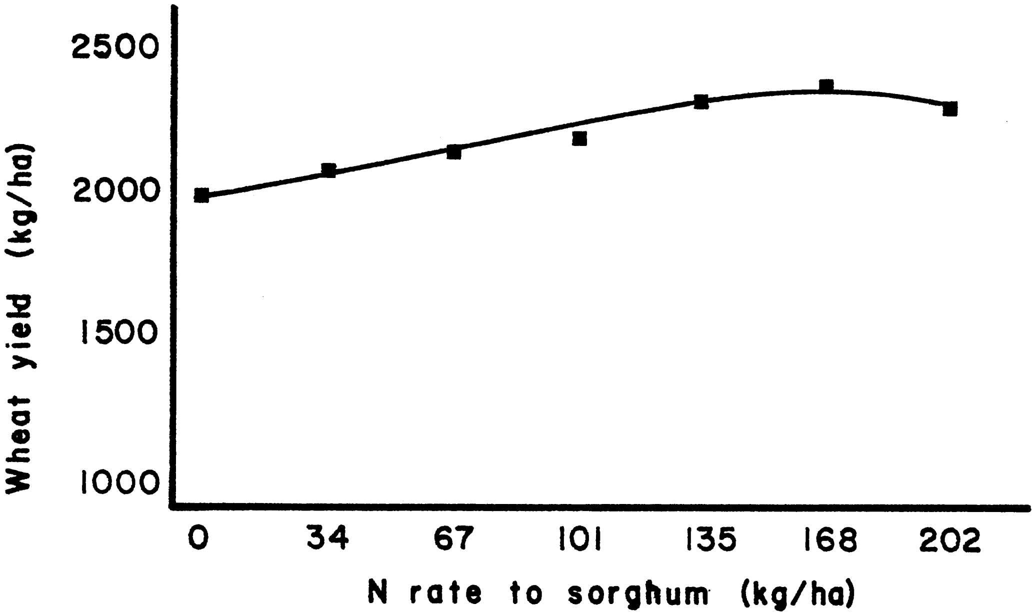


Figure 2. Spring 1980 Wheat Yield Response to Rate of N Applied to Sorghum. Points are the Means For Each Treatment

noted that the yield curve for 1980 fits the top (or more level) portion of a typical yield curve. This is expected since the 90 kg/ha N applied directly to the wheat would push the yield obtained onto the higher portion of the yield curve.

Rainfall for the 1980-1981 growing season was well below average but wheat yield response to the rate of N application to sorghum was significant (OSL = .02, Table V, Appendix). Wheat yields were highest on plots receiving no N to sorghum and decreased as the N rate to sorghum increased up to 135 kg/ha. The yield then increased as N rate to sorghum increased (Figure 3). Normally in a dry year and at N application rates directly to wheat in this experiment, no yield response to residual N would be expected. The wheat yield response at higher N rates to sorghum may have been caused by a delay of the fall N application until five weeks after planting wheat, and no precipitation for a month after N application to carry the applied N into the soil. This could have resulted in wheat absorption and use of residual N in sufficient quantities to make a significant difference in yields.

Greater weed growth as rate of N application to sorghum increased was noted at harvest time and probably reduced wheat yields. Increased soil water depletion by sorghum receiving higher N application rates may also have reduced wheat yields.

Since wheat yield response to N varied from year to year depending on available moisture, a significant (OSL = .002, Table VI, Appendix) N rate to sorghum by year interaction was observed. Average yearly wheat yield differences were significant (OSL = .0001, Table VI, Appendix) as would be expected with the large differences in rainfall during the experiment. The three year average wheat yields were about the same for

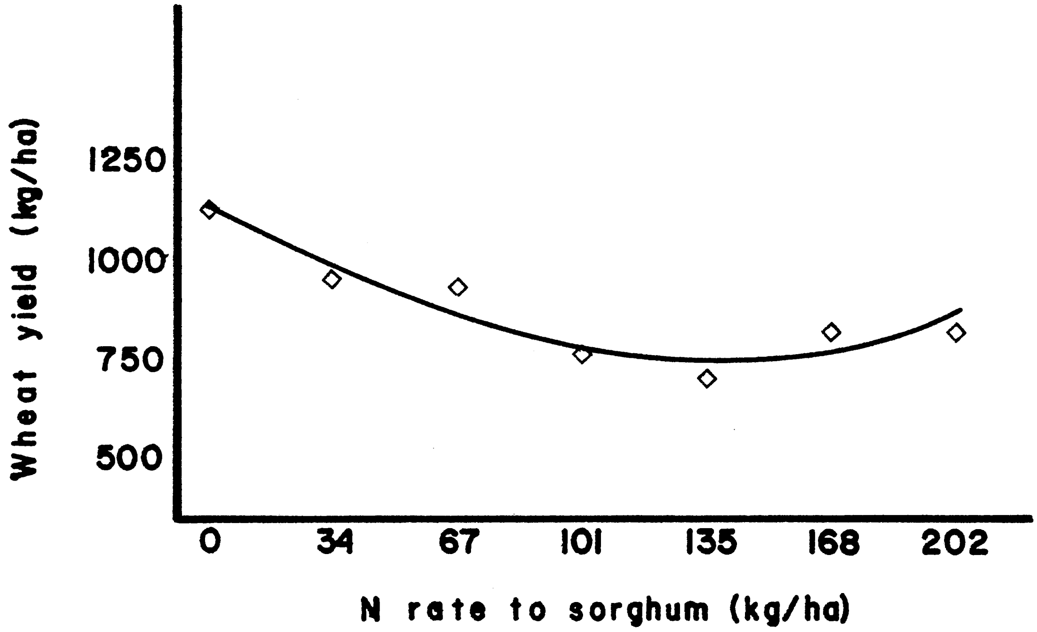


Figure 3. Spring 1981 Wheat Yield Response to Rate of N Applied to Sorghum. Points Are the Means For Each Treatment

all N rate to sorghum treatments (Table II).

TABLE II

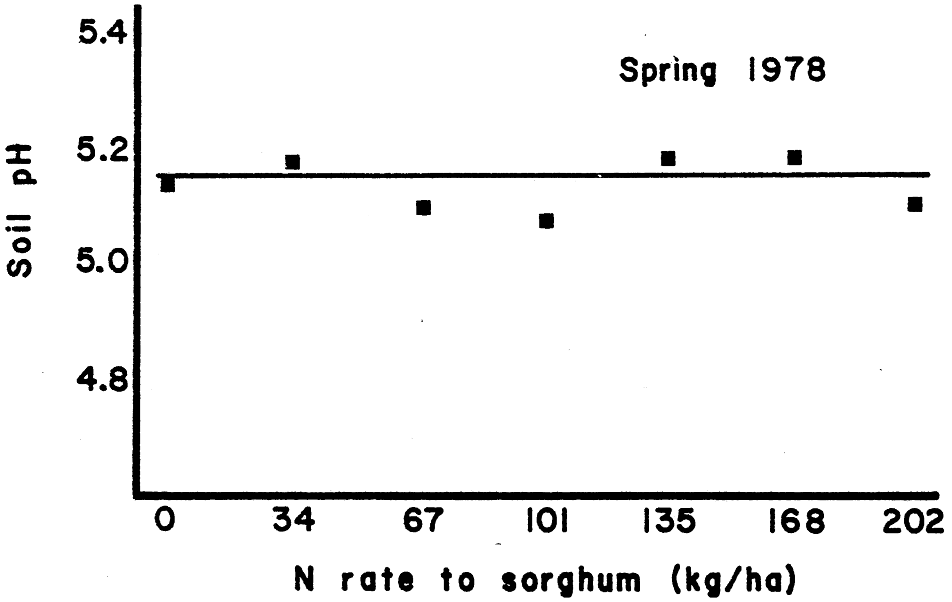
EFFECT OF N APPLICATION RATE TO SORGHUM ON WHEAT YIELDS

Rate of nitrogen application	1979	1980	1981	3 year average
0	2482	1990a*	1144d+	1872
34	2517	2053a	972de	1848
67	2443	2142ac	948def	1844
101	2492	2206abc	711f	1803
135	2318	2312bc	698f	1776
168	2450	2382b	820ef	1884
202	2613	2294bc	815ef	1907
$LSD_{.10}$	192	223	205	213
$LSD_{.05}$	232	270	249	258

Values given are treatment means in kg/ha.
*Values not followed by the same letter are significantly different at the .10 level.
+Values not followed by the same letter are significantly different at the .05 level.

Soil pH

Significant differences in soil pH values (0-15 cm depth) between treatments of N rate to sorghum occurred each year of the experiment (OSL = .001 in spring 1979, OSL = .031 in fall 1979, and OSL = .0001 in fall 1980, Tables VIII-X, Appendix). The pH decreased as the N rate to sorghum increased with the pH decreasing more rapidly per increment of N at high N rates than at low N rates (Figure 4). The regression curve of pH on N rate to sorghum became steeper each succeeding year (as determined by measuring the slope of the tangent to the regression curve). This indicates the effect of N rate to sorghum on pH was cummulative over the three years. The decrease in the pH as applied N increased was expected and has been reported by other researchers (1, 21). Fertilizers containing NH_4^+ release H^+ into the soil upon conversion to NO_3^-, which lowers the soil pH. Not all of the applied NH_4^+ will be converted to NO_3^- as some will be absorbed directly by the plant, some will be immobilized by soil microorganisms, and some will be absorbed onto or fixed by the soil colloids. The H^+ released through conversion of NH_4^+ to NO_3^- will not all remain in the soil solution to influence the active pH of the soil, but will be adsorbed onto soil colloids or lost from the soil, thus buffering the soil pH. As the amount of NH_4^+ increases, more H^+ will be produced, and the ability of the soil system to absorb H^+ and buffer the pH will be reduced, causing a more rapid decrease in active soil pH. This explains why the curves of pH vs. N rate to sorghum are quadratic or cubic downward with uniform increments of applied N instead of horizontal or curved slightly upward as would be the case if the buffering capacity of the soil were constant at all H^+ concentrations. The rate of decline of pH at high levels of applied NH_4NO_3 would be even more noticeable if the pH were not a log function since plotting the log of the H^+ concentration vs. N rate tends to produce a straighter curve



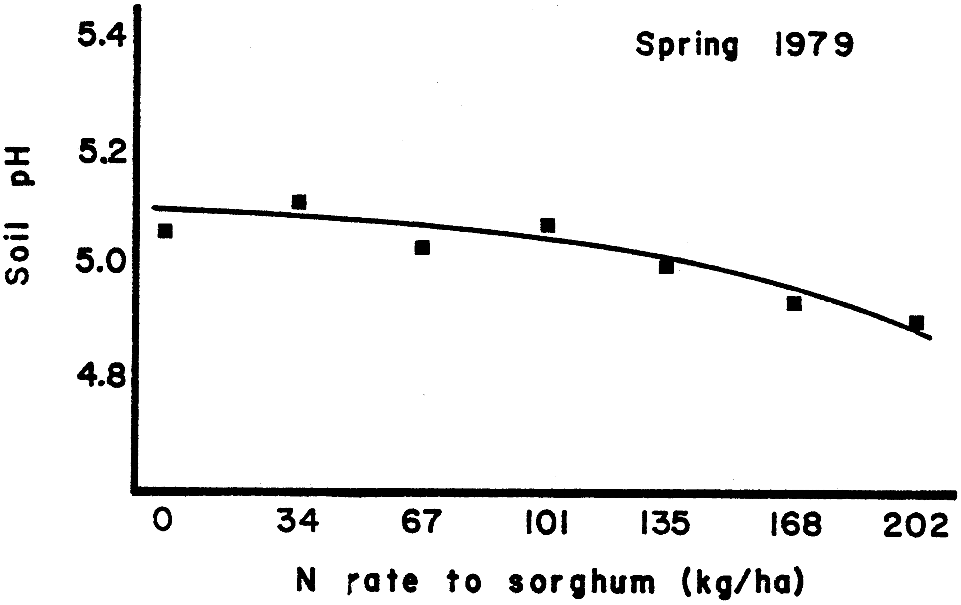
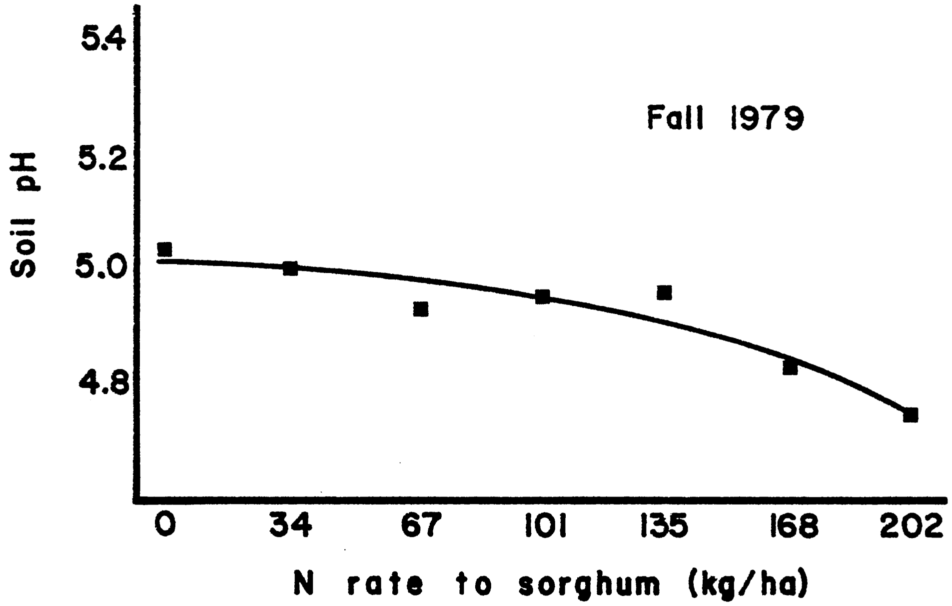


Figure 4. Effect of Rate of N Application to Sorghum on Soil pH in Surface (0-15 cm) Soil. Plot of Treatment Means (Points) and Regression Curves (Lines)



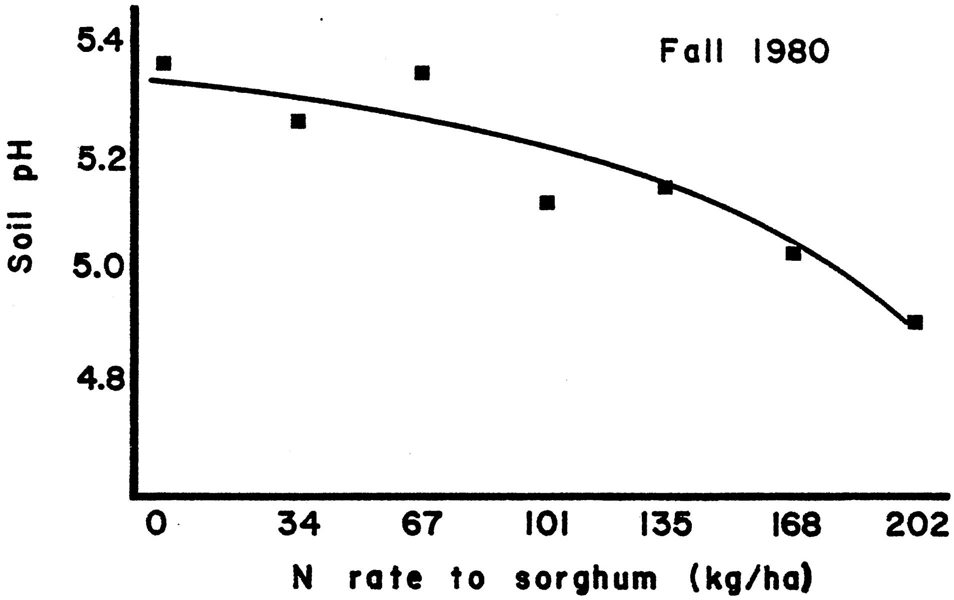


Figure 4. (Continued)

at these H^+ concentrations that plotting H^+ concentration vs. N rate.

It should also be noted that lower soil pH (both active and reserve) means increased costs for lime. Calculations based on the fall 1980 buffer index values indicated that plots that received three annual N to sorghum applications of 168 to 202 kg/ha would need about two metric tons more lime per hectare than plots that received three annual N to sorghum applications of 0 to 67 kg/ha. Excess N applications result in increased N and liming costs without compensating increases in yields. Also, no significant differences in pH were found between treatments of time of N application to wheat.

Sorghum Yields

Only in 1979 was there sufficient summer moisture to produce a sorghum grain crop. Yields increased significantly with each increment (34 kg/ha) of N until 67 kg/ha had been applied, after which yields gradually but insignificantly decreased (Figure 5). With the available moisture and other conditions in 1979, 67 kg/ha was the best N rate for sorghum. At N rates higher than 67 kg/ha the N may have been used by the sorghum for luxury consumption, which may have increased protein content of the grain. At the highest N rates (202, 168 and possibly 135 kg/ha) soil tests indicated NO_3^--N accumulated in the soil, unused by the sorghum crop. Since the sorghum crop failed two out of three years due to lack of moisture, double-cropping without irrigation in this area seems a questionable farming practice.

Residual NO_3^--N in Soil

The soil tests for spring 1979 were taken after one full year of N

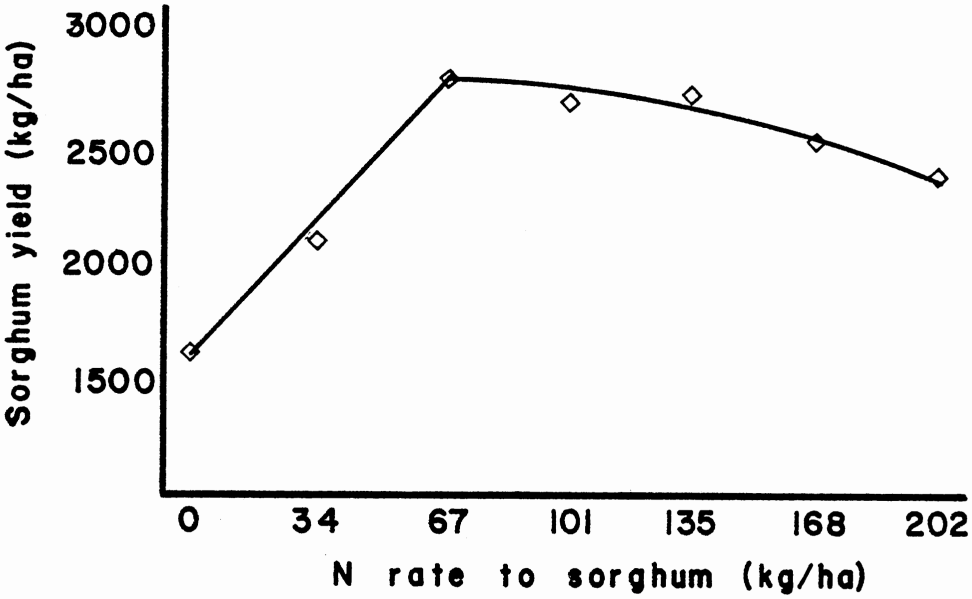


Figure 5. Effect of Rate of N Application to Sorghum on Sorghum Grain Yields 1979. Plot of Treatment Means

treatments to sorghum and wheat. The time of N application to wheat treatments gave no significant differences in soil NO_3^--N levels. Residual NO_3^--N levels for N rate to sorghum treatments were about the same except for the highest N rates (168 and 202 kg/ha) which gave higher residual NO_3^--N values (Figure 6). Most of the N applied to sorghum in 1978 was probably leached to the lower (15- to 75-cm) depths of the soil profile by heavy late spring rains prior to soil sampling. Nitrogen remaining was lost to the environment or used by the wheat crop, leaving little residual NO_3^--N in the surface soil except at high rates of N.

The fall 1979 soil NO_3^--N test was taken after an additional N application to sorghum and a successful sorghum crop that yielded between 1600 and 2800 kg/ha. No significant differences in soil NO_3^--N values for the surface 15 cm occurred among N rate to sorghum treatments except for the highest rates of applied N, as happened in the spring 1979 (Figure 7). Except for high N rates, most of the applied N was probably used by sorghum during the summer or immobilized when sorghum residue was disked into the soil. Again, N applications of 168 to 202 kg/ha were more than required by plants and accumulated in the soil or leached from the top 15 cm of soil.

The analyses of variance (AOVs) for the spring 1979 and fall 1979 residual NO_3^--N values (Tables XI and XII, Appendix) showed a significant interaction (OSL = .004 for spring 1979 and OSL = .046 for fall 1979) between the two treatments (time of N application to wheat and rate of N application to sorghum), but examination of the data showed that the failure of the differences between the means of one treatment to be the same at different levels of the other treatment was caused by two or three scattered means without consistent trends. The scattered mean

Figure 6. Effect of Rate of N Application to Sorghum on Residual NO_3^--N in the Surface (0-15 cm) Soil, Spring 1979. Plot of Treatment Means

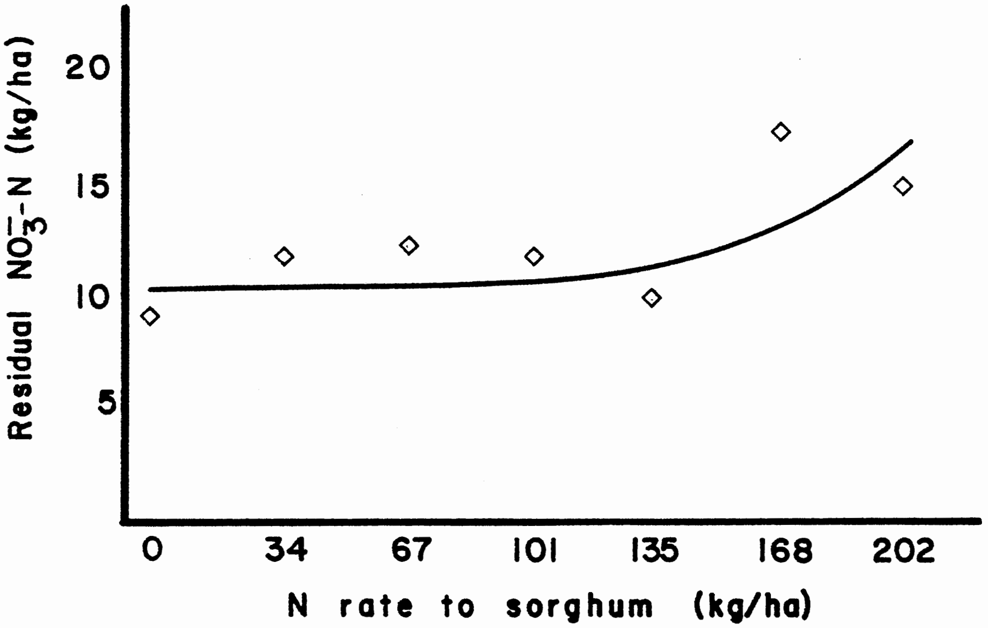


Figure 7. Effect of Rate of N Application to Sorghum on Residual NO_3^--N in the Surface (0-15 cm) Soil, Fall 1979. Plot of Treatment Means

values in the fall 1979 data were not on the same treatment combinations as were the scattered mean values in the spring 1979 data.

The soil was sampled to 75 cm in 15-cm increments in the fall of 1979 to examine the NO_3^--N movement and accumulation patterns. There were no differences in NO_3^--N soil test values attributable to time of N application to wheat treatments, but differences in NO_3^--N soil test values due to N rate to sorghum treatments were evident and statistically significant |(OSL varied with the analysis of each depth but was between .0001 and .05 for all depths and for total accumulated NO_3^--N in the profile; (Tables XIII to XVII, Appendix)|. The pattern of NO_3^--N accumulation as N rate to sorghum increased was about the same at all depths except in the surface 15 cm where crop use and N immobilization would have modified the amount of NO_3^--N accumulation, as explained earlier. More NO_3^--N accumulated at deeper depths and at higher N rates to sorghum (Figure 8). Total accumulations did not become significantly larger (at the .05 level) than the check plots until N rate to sorghum reached or exceeded 135 kg/ha. Notice in Figure 9 that at low levels of applied N there is no increase in the amount of accumulated N in the soil profile until the 45 to 75 cm depth is reached. This indicates little leaching of N to lower soil depths at low N application rates when the sorghum crop was growing on the field. The NO_3^--N accumulated at the 45- to 75-cm depths would have come from N applications to sorghum in 1978 because there was neither the time nor the moisture necessary to leach the N applied in 1979 to these depths. At high levels of N application to sorghum, increases of NO_3^--N accumulation at the 15- to 30-cm and 30- to 45-cm depths indicate leaching of the N applied in 1979. This shows N rates greater than 135 kg/ha were excessive even in

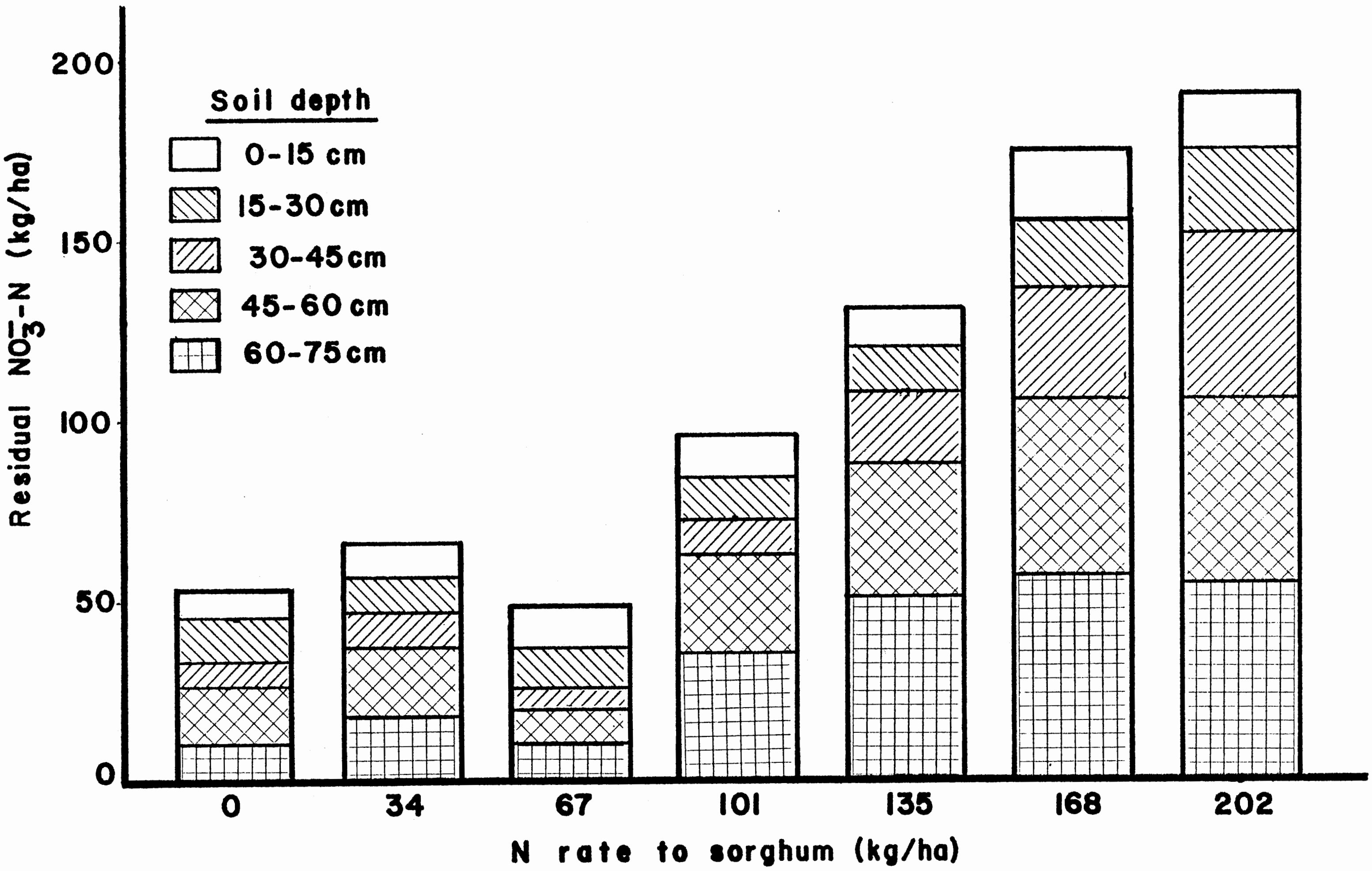


Figure 8. Effect of Rate of N Application to Sorghum on Residual NO_3^--N Accumulation in Soil Profile (0-75 cm), Fall 1979

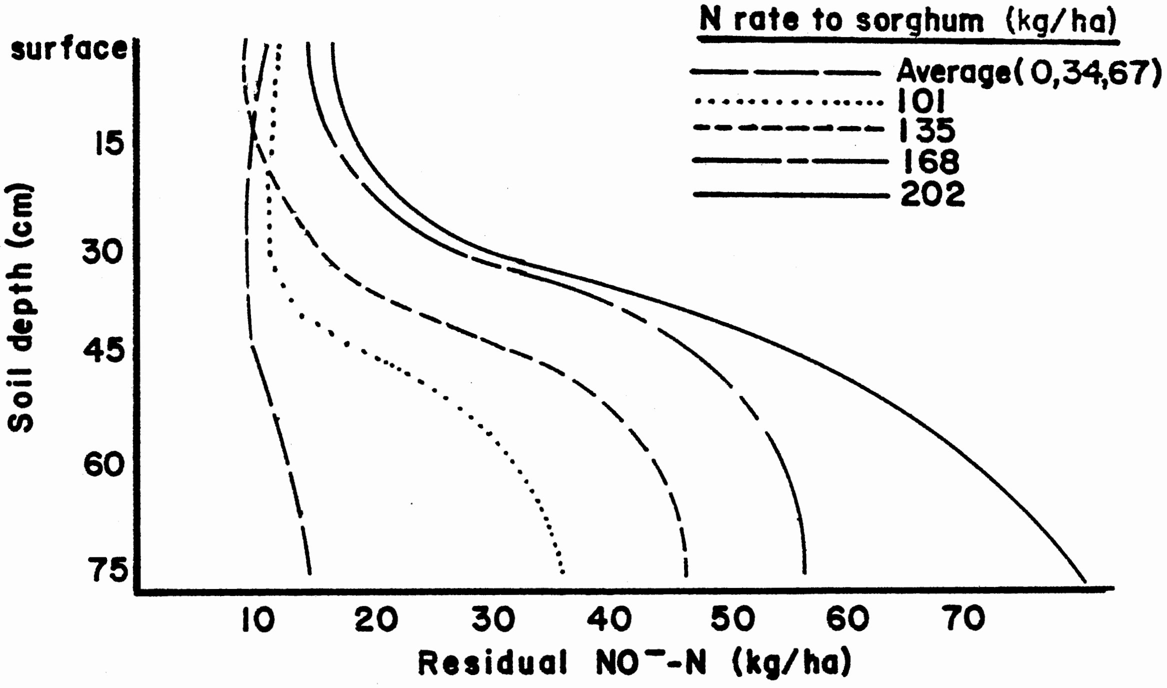


Figure 9. Residual NO_3^--N in Soil Profile at Different Depths For Different N Rates to Sorghum, Fall 1979

a year with above average precipitation. There is about 68 kg/ha difference between the N rate producing top sorghum yields (67 kg/ha) and the N rate at which N began to leach from the soil surface (135 kg/ha). Some of this N was probably used in luxury consumption by the sorghum.

The fall 1980 soil samples were taken after another full year of N treatments and a failure of the sorghum crop. Accumulation of N in the soil profile was slightly lower in fall 1980 than in fall 1979 but followed the same general pattern of accumulation (Figures 10 and 11) with significant differences in soil NO_3^--N among N rate to sorghum treatments (OSL = .004 for surface 15 cm, OSL<.001 for 15 to 75-cm depths and for total accumulated NO_3^--N; Tables XVIII to XXIII, Appendix) and leaching only at the higher N rates (Figure 12). Even though the sorghum crop failed to produce grain, there was considerable vegetative growth and much of the N applied to the sorghum and some N from the lower 15 to 75 cm of the soil profile were probably absorbed by the sorghum. This N would not have been released from the plant residues before the soil samples were taken and would not show up in the soil NO_3^--N test. Over five weeks elapsed between the time of planting wheat and sampling the soil in fall 1980. Some of the available N that was not absorbed by the sorghum may have been immobilized by microorganisms decomposing sorghum residues or absorbed by the wheat crop before the soil was sampled, further reducing the amount of NO_3^--N left in the soil. This is a plausible explanation why no year to year increase was seen in NO_3^--N in the soil even at high N rates to sorghum.

Deep (90 to 120 cm) soil samples taken in the fall of 1980 showed soil NO_3^--N levels decreased with depth below the 90-cm depth. The soil profile has a thick clay horizon starting at about 50 to 100 cm. This

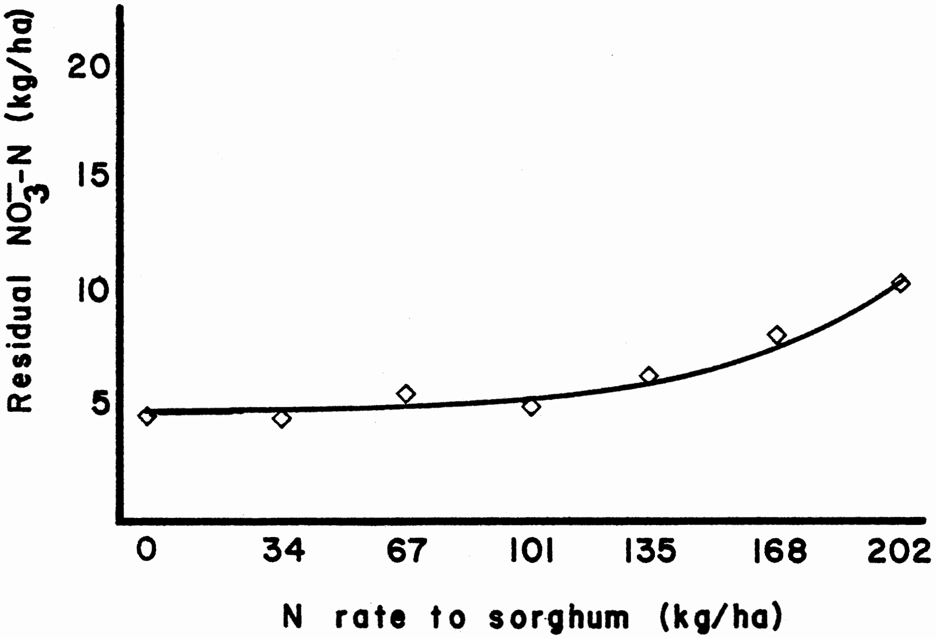


Figure 10. Effect of Rate of N Application to Sorghum on Residual NO_3^--N in the Surface (0-15 cm) Soil, Fall 1980. Plot of Treatment Means

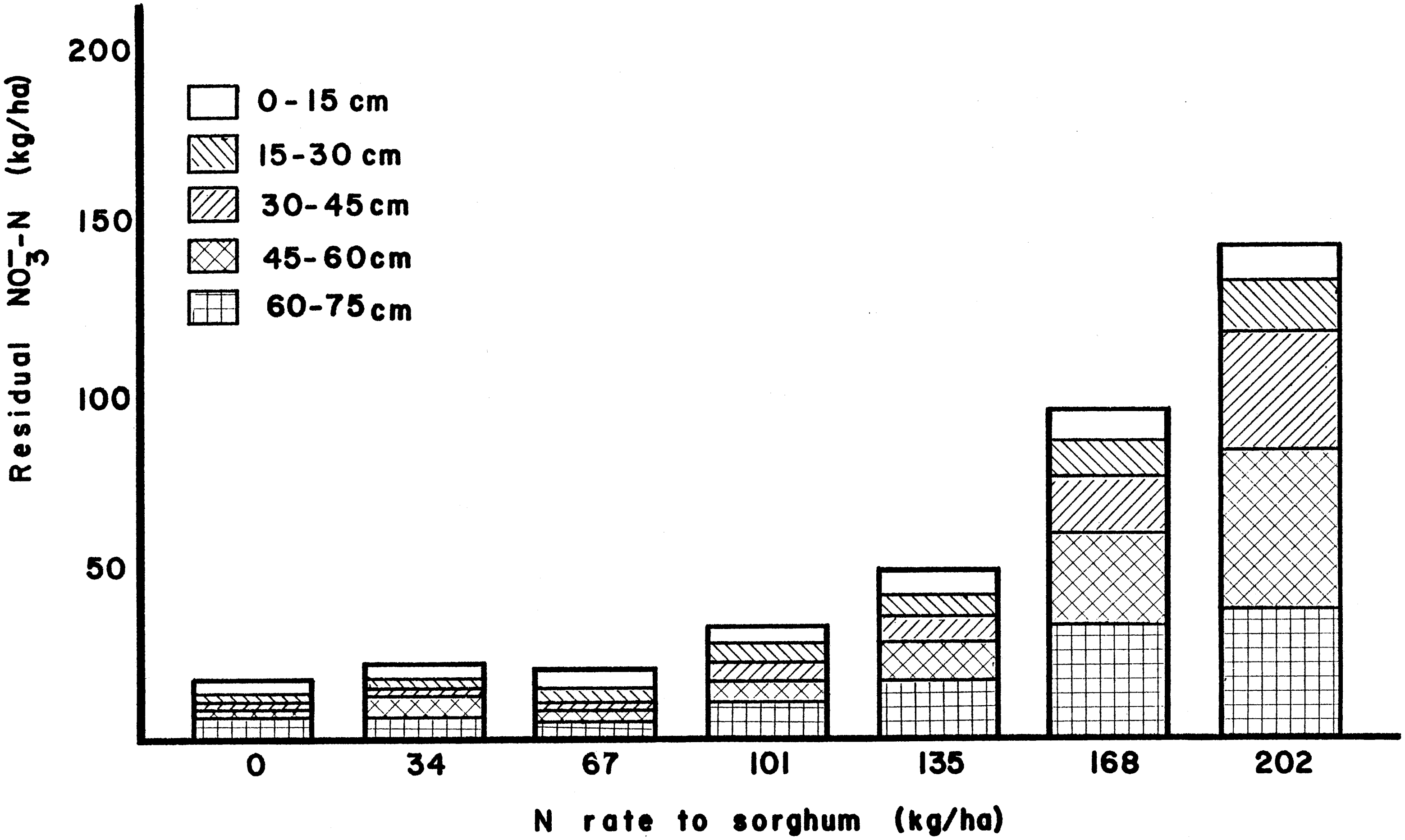


Figure 11. Effect of Rate of N Application to Sorghum on Residual NO_3^--N Accumulation in Soil Profile (0-75 cm), Fall 1980

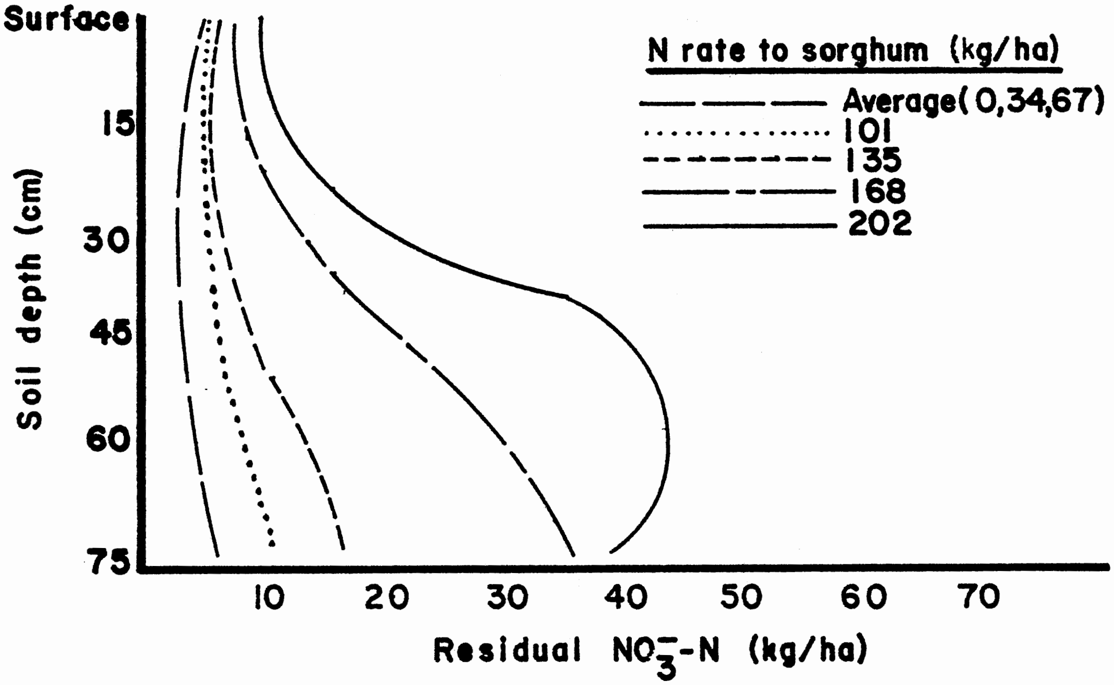


Figure 12. Residual NO_3^--N in Soil Profile at Different Depths for Different N Rates to Sorghum, Fall 1980

clay layer is slowly permeable to water so NO_3^--N tends to accumulate above it, keeping most of the leached NO_3^- from deep percolation and, for the most part, keeping it within reach of crop roots.

A significant interaction (OSL = .004, Table XVIII, Appendix) between N rate to sorghum and time of N application to wheat treatments was found for NO_3^--N levels in the surface soil in the fall of 1980. At high levels of N rate to sorghum, N applied to wheat in the spring produced more residual NO_3^--N than did N applied to wheat in the fall. A possible explanation is that wheat fertilized in the fall produced a greater yield and, therefore, absorbed more N than wheat fertilized in the spring. This would leave less residual NO_3^--N in the plots that were fertilized in the fall.

CHAPTER V

SUMMARY AND CONCLUSIONS

A field experiment was conducted at the Eastern Research Station near Haskell, Oklahoma, from June 1978 to June 1981 to determine how time of N application to wheat and N rate applied to sorghum affected wheat and grain sorghum yields, soil pH, and accumulation of NO_3^--N in the soil profile, on a wheat-grain sorghum double-cropping system.

Over the three years of the experiment, fall N applications to wheat produced higher average wheat grain yields every year than spring or split (half fall and half spring) N applications. This was probably because fall N applications eliminated N deficiencies caused by immobilization of N by incorporated sorghum residues. Grain sorghum yields, soil pH, and accumulation of NO_3^--N in the soil profile were not affected by time of N application to wheat.

Residual N from N rate applied to sorghum treatments affected wheat yield differently each year. There were no wheat yield responses to N rates applied to sorghum in the year of average moisture because N applied directly to wheat supplied sufficient N to meet the wheat's growth requirements. In the wet year the wheat was able to use N in addition to the 90 kg/ha applied directly to the wheat and wheat yields increased slowly as N rate to sorghum increased. In the dry year wheat yields decreased as N rate to sorghum increased, probably due mostly to increased weed competition at high N rates. Averaged over the three years, there were no significant differences between wheat yields for N rate applied to sorghum treatments.

In only one year in three was there enough rainfall to produce a sorghum grain crop. In that year (1979) a N application rate of 67 kg/ha produced the highest sorghum grain yields and resulted in the least residual soil NO_3^--N of any treatment. Soil pH decreased and NO_3^--N accumulation in the soil increased as N rate applied to sorghum increased, with the rate of change more rapid per increment of N at high N treatment levels than at low N treatment levels.

Results from this three year experimental period show that double-cropping wheat and grain sorghum may not be justified on the Taloka soil in this area of Oklahoma due to insufficient available moisture.

According to the data collected in these three years, available moisture may not be sufficient in this area of Oklahoma to justify double-cropping of wheat and grain sorghum. If double-cropping is attempted under rainfed conditions, the N application to wheat should be made in the fall and high N rates to sorghum (>67 kg/ha from our data) should not be used as this will increase N and liming costs without a compensating yield increase. Since rainfall patterns vary from year to year this conclusion is subject to change for other years or weather patterns.

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TABLE III

ANALYSIS OF VARIANCE TABLE FOR WHEAT YIELD 1979

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	83	6190125			
Rep	3	198384			
N rate to sorghum (A)	6	569238	94873	1.30	.309
Error (a)	18	1318540	73277		
Time of N to Wheat (B)	2	1458690	729345	4.47	.065
Error (b)	6	978219	163086		
A X B	12	512344	42745	1.33	.244
Error (c)	36	1154710	32021		

TABLE IV

ANALYSIS OF VARIANCE TABLE FOR WHEAT YIELD 1980

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	83	6101359			
Rep	3	520982			
N rate to sorghum (A)	6	1479393	246640	2.48	.063
Error (a)	18	1789926	99490		
Time of N to wheat (B)	2	480769	240385	2.33	.178
Error (b)	6	618238	103064		
A X B	12	408683	34107	1.53	.160
Error (c)	36	803218	22341		

TABLE V

ANALYSIS OF VARIANCE TABLE FOR WHEAT YIELD 1981

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	83	9268507			
Rep	3	1283987			
N rate to sorghum (A)	6	1826863	304427	3.62	.016
Error (a)	18	1514691	84149		
Time of N to Wheat (B)	2	1391669	695834	2.08	.206
Error (b)	6	2006928	334513		
A X B	12	478833	39915	1.88	.072
Error (c)	36	765537	21298		

TABLE VI

ANALYSIS OF VARIANCE TABLE FOR WHEAT YIELD 1979-1981

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	251	144599490			
Rep	3	1143093			
N rate to sorghum (A)	6	456045	75958	0.84	.554
Error (a)	18	1624308	90256		
Time of N to Wheat (B)	2	3090148	1545074	2.99	.126
Error (b)	6	3103105	517259		
Year (Y)	2	123039500	61519822	429.04	.0001
Error (c)	6	860261	143426		
A X B	12	420598	35000	1.09	.398
Error (d)	36	1158135	32170		
A X Y	12	3419448	284917	3.42	.002
Error (e)	36	2998998	83256		
B X Y	4	240980	60171	1.45	.279
Error (f)	12	500280	41702		
A X B X Y	24	979411	40809	1.88	.022
Error (g)	72	1565329	21745		

TABLE VII

ANALYSIS OF VARIANCE TABLE FOR SORGHUM YIELDS 1979

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	80	33257065			
Rep	3	1322115			
N rate to sorghum (A)	6	11722246	1953608	4.74	.005
Error (a)	18	7418261	412109		
Time of N to Wheat (B)	2	262129	131065	0.59	.583
Error (b)	6	1328072	221321		
A X B	12	1331349	110958	0.37	.965
Error (c)	33	9872893	299215		

TABLE VIII

ANALYSIS OF VARIANCE TABLE FOR SOIL pH, SPRING 1979

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	83	2.3242			
Rep	3	0.3432			
N rate to sorghum (A)	6	0.4883	.0747	6.13	.001
Error (a)	18	0.2193	.0122		
Time of N to Wheat (B)	2	0.0245	.0082	0.15	.867
Error (b)	6	0.5021	.0837		
A X B	12	0.1188	.0099	0.53	.878
Error (c)	36	0.6679	.0186		

TABLE IX

ANALYSIS OF VARIANCE TABLE FOR SOIL pH, FALL 1979

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	83	4.9556			
Rep	3	2.0537			
N rate to sorghum (A)	6	0.7598	.1266	3.04	.031
Error (a)	18	0.7488	.0416		
Time of N to Wheat (B)	2	0.0088	.0044	0.25	.785
Error (b)	6	0.1045	.0174		
A X B	12	0.3445	.0287	1.10	.386
Error (c)	36	0.9355	.0260		

TABLE X

ANALYSIS OF VARIANCE TABLE FOR SOIL pH, FALL 1980

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	83	4.5867			
Rep	3	0.3276			
N rate to sorghum (A)	6	2.0467	.3411	10.73	.0001
Error (a)	18	0.5724	.0318		
Time of N to Wheat (B)	2	0.1131	.0565	1.58	.281
Error (b)	6	0.2145	.0358		
A X B	12	0.3169	.0264	0.96	.507
Error (c)	36	0.9955	.0277		

TABLE XI

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (0 - 15 cm), SPRING 1979

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	83	2467.42			
Rep	3	30.30			
N rate to sorghum (A)	6	511.92	85.32	2.16	.096
Error (a)	18	709.51	39.42		
Time of N to Wheat (B)	2	56.19	28.09	2.18	.194
Error (b)	6	77.30	12.89		
A X B	12	577.74	46.48	3.19	.004
Error (c)	36	524.48	14.57		

TABLE XII

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (0 - 15 cm), FALL 1979

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	83	3365.51			
Rep	3	1456.69			
N rate to sorghum (A)	6	549.42	91.57	5.04	.003
Error (a)	18	327.07	18.17		
Time of N to wheat	2	6.30	3.15	0.19	.832
Error (b)	6	99.78	16.63		
A X B	12	378.41	31.54	2.07	.046
Error (c)	36	547.83	15.22		

TABLE XIII

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (15 - 30 cm), FALL 1979

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	80	6401.65			
Rep	3	867.82			
N rate to sorghum (A)	6	1807.57	301.26	8.84	.0001
Error (a)	18	613.11	34.06		
Time of N to wheat	2	93.17	45.58	1.03	.413
Error (b)	6	271.71	45.29		
A X B	12	1041.59	86.79	1.68	.118
Error (c)	33	1706.66	51.72		

TABLE XIV

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (30 - 45 cm), FALL 1979

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	81	70263.7			
Rep	3	865.4			
N rate to sorghum (A)	6	19064.6	3177.5	4.90	.004
Error (a)	18	11677.0	648.7		
Time of N to wheat (B)	2	4592.2	2296.1	2.56	.157
Error (b)	6	5375.2	895.8		
A X B	12	16824.2	1402.1	4.02	.001
Error (c)	34	11865.0	349.0		

TABLE XV

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (45 - 60 cm), FALL 1979

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	78	131628.9			
Rep	3	1035.3			
N rate to sorghum (A)	6	28886.4	4814.4	2.69	.048
Error (a)	18	32259.8	1792.3		
Time of N to wheat (B)	2	3447.3	1723.7	0.67	.545
Error (b)	6	15372.6	2562.1		
A X B	12	13527.1	1127.3	0.94	.520
Error (c)	31	37100.2	1196.7		

TABLE XVI

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (60 - 75 cm), FALL 1979

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	78	115326.6			
Rep	3	3027.7			
N rate to sorghum (A)	6	40774.1	6795.7	4.45	.006
Error (a)	18	27473.9	1526.3		
Time of N to wheat (B)	2	203.7	101.9	0.16	.856
Error (b)	6	3840.1	640.0		
A X B	12	9946.9	828.9	0.85	.598
Error (c)	31	30060.3	969.7		

TABLE XVII

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (0 - 75 cm), FALL 1979

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	75	602665.9			
Rep	3	8081.8			
N rate to sorghum (A)	6	196491.2	32748.5	4.57	.006
Error (a)	18	128991.8	7166.2		
Time of N to wheat (B)	2	13416.4	6708.3	0.91	.453
Error (b)	6	44450.0	7408.3		
A X B	12	84899.7	7075.0	1.57	.159
Error (c)	28	126334.9	4512.0		

TABLE XVIII

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (0 - 15 cm), FALL 1980

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	79	1115.21			
Rep	3	112.15			
N rate to sorghum (A)	6	319.62	53.27	4.90	.004
Error (a)	18	195.73	10.88		
Time of N to wheat (b)	2	27.79	13.90	0.95	.438
Error (b)	6	87.85	14.64		
A X B	12	203.06	16.92	3.20	.004
Error (c)	32	168.99	5.29		

TABLE XIX

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (15 - 30 cm), FALL 1980

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	79	2195.5			
Rep	3	100.2			
N rate to sorghum (A)	6	1273.9	212.3	12.99	.0001
Error (a)	18	294.3	16.3		
Time of N to wheat (B)	2	8.0	4.0	0.22	.809
Error (b)	6	108.7	18.1		
A X B	12	146.5	12.2	1.48	.183
Error (c)	32	263.9	8.2		

TABLE XX

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (30 - 45 cm), FALL 1980

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	80	13765.4			
Rep	3	89.2			
N rate to sorghum (A)	6	9530.4	1588.4	33.87	.0001
Error (a)	18	844.1	46.9		
Time of N to wheat (B)	2	0.6	0.3	0.00	.996
Error (b)	6	452.6	75.4		
A X B	12	380.7	31.7	0.42	.943
Error (c)	33	2468.1	74.8		

TABLE XXI

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (45 - 60 cm), FALL 1980

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	81	35329.0			
Rep	3	527.7			
N rate to sorghum (A)	6	18685.1	3114.2	21.14	.0001
Error (a)	18	2651.8	147.3		
Time of N to wheat (B)	2	385.9	193.0	0.32	.737
Error (b)	6	3605.2	600.9		
A X B	12	2842.3	236.9	1.21	.313
Error (c)	34	6631.0	195.0		

TABLE XXII

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (60 - 75 cm), FALL 1980

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	79	29212.8			
Rep	3	474.3			
N rate to sorghum (A)	6	12333.7	2055.6	6.60	.001
Error (a)	18	5602.2	311.2		
Time of N to wheat (B)	2	128.2	64.1	0.29	.760
Error (b)	6	1337.0	222.8		
A X B	12	3345.3	278.8	1.49	.180
Error (c)	32	5991.9	187.2		

TABLE XXIII

ANALYSIS OF VARIANCE TABLE FOR SOIL NITRATE (0 - 75 cm), FALL 1980

Source	Degrees of Freedom	Sum of Squares	Mean Square	F ratio	OSL
Total	68	213110.7			
Rep	3	3494.2			
N rate to sorghum (A)	6	141283.8	23547.3	16.21	.0001
Error (a)	18	26149.4	1452.7		
Time of N to wheat (B)	2	2481.4	1240.7	0.63	.566
Error (b)	6	11867.3	1977.9		
A X B	12	7486.4	623.9	0.64	.783
Error (c)	21	20348.2	969.0		

VITA

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