

## **Chapter 4**

### **Residual Profile Mineral-N Influence on Sorghum Response to Applied Nitrogen**

## **Residual Profile Mineral-N Influence on Sorghum Response to Applied Nitrogen**

### **ABSTRACT**

The contribution of residual profile mineral-N to crop response is often neglected in humid climatic conditions. This neglect appears to be, in part, due to the still widely accepted perception that over-winter soil mineral-N losses are high in humid regions. The objective of this study was to examine the effect of soil mineral-N on sorghum response to N fertilization, and to determine if soil mineral-N can be considered as a part of an N fertilizer recommendation program. Multi-location field studies were conducted during three years (1995, 1996, and 1997). Experimental plots were selected each year on farmer's fields at different locations in the Virginia Coastal plain. Fields were selected based on preliminary soil testing of surface samples for soil N levels. Soil samples for profile mineral-N ( $\text{NO}_3\text{-N}$  and  $\text{NH}_4\text{-N}$ ) were collected to a depth of 1.2 m at planting and side dressing (~ 35 days after planting). Fertilizer treatments consisted of factorial combinations of four starter band, and four side-dress N rates to supply a total of ten different N fertilization levels of 11, 34, 56, 78, 101, 123, 146, 168, 190, and 213 kg N ha<sup>-1</sup>. The experiment design was a randomized complete block with four replicates. Soil mineral-N levels varied from 83 to 131 kg N ha<sup>-1</sup> at planting and from 72 to 197 kg N ha<sup>-1</sup> at side dressing and contributed substantially to the N needs of the grain sorghum crop. The grain yield increase due to applied N ranged from 2.03 to 4.92 Mg ha<sup>-1</sup> and was inversely correlated with residual soil mineral-N measured to a soil depth of 0.9m at planting. In order to consider residual soil mineral-N in making N fertilizer recommendations "Associated Nitrogen Fertilizer Equivalency" (ANFE) values were calculated. ANFE is the amount of applied N that has potential to produce the same yield as that produced by the residual soil mineral-N. The ANFE values were then deducted from the crop N fertilizer requirements based on realistic yield goal set for a specific field under consideration. The N fertilizer recommendations based on ANFE values were quite close for two out of four sites as compared to the N rates at which the

maximum yields were obtained in this study. The ANFE fertilizer recommendation rates were 41 and 45 kg ha<sup>-1</sup> more efficient as compared to the traditional method of N fertilizer recommendation based on yield goal. However, the ANFE system over and under predicted the required N rates for one site each. More research is needed on several different sites with varying levels of residual soil mineral-N to develop a stronger relationship between soil mineral-N and the ANFE values. The data indicates that the ANFE concept has potential for including soil mineral-N as an integral part of the fertilizer N recommendation system in the humid mid-Atlantic region.

## INTRODUCTION

The contribution of residual profile mineral-N to crop response is often neglected in humid climatic conditions. This neglect appears to be, in part, due to the still widely accepted perception that over-winter soil mineral-N losses are high in humid regions through leaching and denitrification (Bundy and Malone, 1988; Scharf and Alley, 1994). Nitrogen (N) fertilization in humid regions, the mid-Atlantic and southeastern states in particular, is more critical than for any other region in the United States (Gilliam and Boswell, 1984). The potential for N leaching is high in this region, as many crops are grown on sandy coastal plain soils. These soils are well drained, fine loamy, siliceous, thermic Paleudults, with low organic matter content (generally <2%) and have sandy to sandy loam surface. Therefore it is generally assumed that profile mineral-N in this region is too transient to permit reliable use of profile mineral-N data for prediction of crop response to N fertilization (Gilliam and Boswell, 1984).

However, increased environmental concerns in the last two decades and the frequency of drought occurrence in the mid-Atlantic region over the last 15 years, have drawn scientific attention towards more efficient use of available resources (soil, water and nutrients). This concern has brought changes in production practices from conventional till, to reduced tillage, to no-till, for conservation of soil and water; and also an increase in adaptation of more water-use-efficient crops like sorghum. These changes suggest the possibility of accumulation of residual N, as reported by several workers (Jolley and Pierre, 1977; Kitur et al., 1984; Power et al., 1986; Timmons and Cruse, 1990 and 1991). The need to evaluate the effects of profile mineral-N on crop response to N fertilization in humid regions has been reported by several workers (Stanford, 1982; Fox and Piekielek, 1984; Meisinger, 1984; Bundy and Malone, 1988), but has largely been ignored due to the widely held perception that high annual precipitation in this region leaches mineral-N from the soil profile.

Substantial research has been done and several procedures have been recommended to test for N availability and predict crop response to N fertilization (Keeney, 1982; Stanford, 1982; Magdoff et al., 1984; Iversen et al., 1985). However, none of these procedures have been widely adopted in humid regions, in states east of Mississippi (Bandel and Fox, 1984; Gilliam and Boswell, 1984; Welch, 1984; Bundy and Malone, 1988). The N fertilizer recommendation for a specific field crop has been largely based on estimates derived from cropping history, yield goal, soil type, and manure management information provided by farmers (Voss, 1982; Magdoff et al., 1984). Currently, the tissue test-based N recommendations in Virginia (Alley et al., 1989) and the soil nitrate test-based recommendations in Maryland, appear to be the only test-based field-specific N rate recommendations in use for crop production in this region (Hergert, 1987). However, the rapid spread of the pre-sidedress soil nitrate test for corn (Blackmer et al., 1989; Fox et al., 1989) shows promise and attests to the viability of soil mineral-N for predicting crop responsiveness in humid regions of the U.S.

Although several studies have reported significant effects of residual soil mineral-N on crop response in humid regions (Meisinger et al., 1987; Bundy and Malone, 1988; Fox et al., 1989; Scharf and Alley, 1994) none of them have used or suggested any mechanism that would account for soil mineral-N while making fertilizer recommendations. This is probably because of (i) variability in the levels of reported soil mineral-N; (ii) only a few studies in humid regions support this observation; and the most important of all (iii) the uncertainty in equating the soil mineral-N values to a given quantity of N fertilizer.

Hanway and Dumenil, (1955) in Iowa, appear to be the first to use soil test results for mineralizable N to predict the most profitable N rate for field corn. Pierre et al. (1977) in Iowa also made an attempt and used a diagnostic test for percent N in

corn grain at harvest in conjunction with the N-requirement index to predict optimum rate of N for corn. Although the N-requirement index approach by Pierre et al. (1977) was successful in predicting optimum rate of N, it did not provide any opportunity during the growing season to correct for below optimum N levels. This approach by Pierre et al. (1977) completely disregarded soil-N. Later, Roberts et al. (1980) in Washington State modified the N-requirement index approach as suggested by Pierre et al. (1977), and developed a response function technique for interpreting soil  $\text{NO}_3$  test as a guide to N fertilization of sweet corn. Onken et al. (1985) in Texas demonstrated the use of the N-requirement index approach, as suggested by Roberts et al. (1980) for irrigated corn. However, all the research work reported above has been performed (i) on grain corn, (ii) in states west of Mississippi River, and (iii) does not suggest any method of equating residual soil profile mineral-N values to a given quantity of N fertilizer.

A systematic approach for interpreting residual soil profile mineral-N value is needed in the mid-Atlantic and southeastern humid regions that eliminates the practice or uncertainty of equating soil-N test results to a quantity of N fertilizer. A mechanism that accounts for soil mineral-N when making fertilizer recommendations is imperative for more efficient use of N. Also, no information is currently available on the effect of residual soil mineral-N on grain sorghum in the humid mid-Atlantic region.

The objectives of this study were to evaluate the influence of residual soil profile mineral-N ( $\text{NO}_3\text{-N}$  and  $\text{NH}_4\text{-N}$ ) on sorghum response to applied N fertilization, to determine if agronomically significant levels of residual mineral-N exist in fields used for grain sorghum production in rotation with winter wheat and double crop soybean, and to consider a system that could account for soil mineral-N in making N fertilizer recommendations for grain sorghum production in Virginia.

## MATERIALS AND METHODS

Multi-location field studies were conducted to determine the effects of residual profile mineral-N on sorghum yield response to applied N over a period of three years (1995, 1996, and 1997). Experimental plots were selected each year on farmer's fields at different locations in the Virginia Coastal plain. Fields were selected based on preliminary soil testing of surface samples for soil N levels. This was done to identify and select sites, such that each site has a different level of soil mineral-N. These sites were representative of the soils (loamy sand or sandy loam, with low available water holding capacity and <2% organic matter) typical of those widely used for grain sorghum production in Virginia and the mid-Atlantic region.

Soil samples for profile mineral-N were collected prior to planting in the month of May and then 30-35 days after planting (DAP) immediately prior to side-dressing at the eight-leaf growth stage of sorghum plants when the rapid N uptake by the crop begins (Vanderlip, 1993). Soil sampling was done with the "JMC Backsaver" soil probe, at increments of 0.15 m for the first two depths, followed by increments of 0.3 m to a 1.2m depth. Sampling at each location consisted of 16 well-spaced cores taken to a depth of 1.2m, composited, mixed thoroughly and frozen immediately after sampling in the field using dry ice. These samples were thawed and air-dried and passed through a sieve of 2 mm diameter. Sieved soil samples were extracted in duplicate with 2M KCl (Keeney and Nelson, 1982).

Nitrate in the soil extracts was determined colorimetrically with a QuikChem Automated Ion Analyzer according to QuikChem Method No. 12-107-04-1-B (Lachat Instruments, Milwaukee, WI), a Griess-Ilosvay method (Keeney and Nelson, 1982). Ammonium in the soil extracts was also measured colorimetrically with the same instrument and QuikChem Method No. 12-107-06-2-A. Soil nitrate and ammonium

contents were calculated (dry weight basis) as  $\text{kg ha}^{-1}$  based on the analyzed soil bulk densities for each corresponding depth. Samples were re-extracted when the difference between the duplicates was larger than 5 percent.

Urea ammonium nitrate (30% N) solution was used as a source of fertilizer N. Treatments consisted of factorial combinations of four starter band, and four side-dress N rates to supply a total of ten different N fertilization rates of 11, 34, 56, 78, 101, 123, 146, 168, 190, and 213  $\text{kg N ha}^{-1}$ . Experimental design at all locations was a randomized complete block with four replicates. Each plot consisted of eight 0.15 m wide rows, 7.62 m in length. Sorghum grain yield was determined by harvesting four middle rows of each plot with a small plot combine. Grain yields are reported at 140  $\text{g kg}^{-1}$  moisture content.

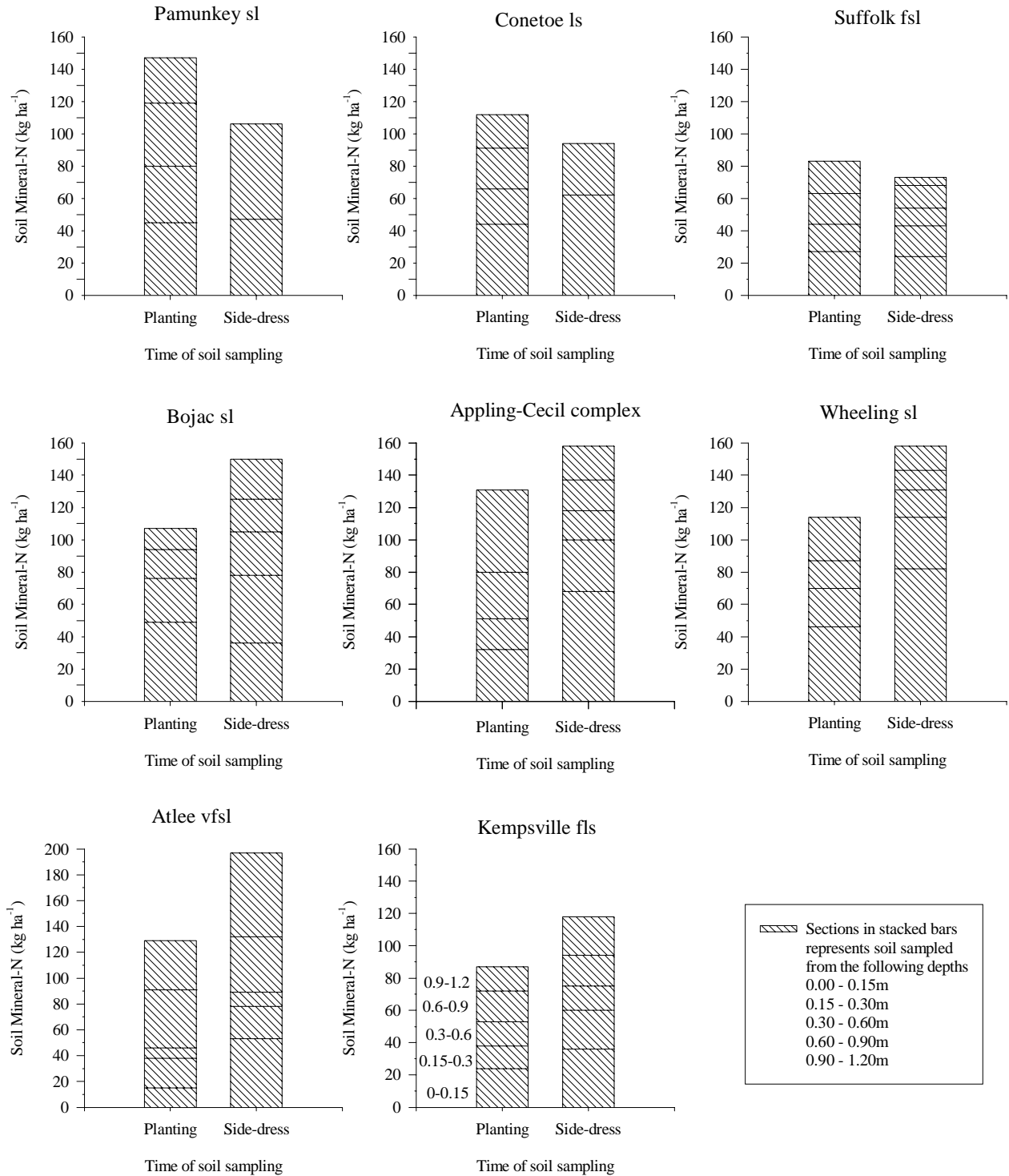
The effect of the residual soil mineral-N on grain sorghum yield increase due to applied N was calculated as the difference between grain yield with zero N fertilizer and the maximum yield on the response curve (SAS Institute, 1993). The yield increase was then correlated with residual soil mineral-N. In order to consider residual soil mineral-N in making N fertilizer recommendations "Associated Nitrogen Fertilizer Equivalency" (ANFE) values were calculated. ANFE is the amount of applied N that has potential to produce the same yield as that produced by the residual soil mineral-N. Two response functions were developed to calculate the ANFE values (i) relative grain yield or percent of maximum yield at the various levels of soil mineral-N and (ii) relative grain yield as a function of various rates of N fertilization. Regression equations for each response function were termed as Equation 1 and Equation 2, respectively. In order to test the validity of estimated ANFE values, soil mineral-N values that we observed in these experiments were substituted in the first response function, Equation 1 to calculate the relative yield values. These relative yield values were then substituted in the second response function, Equation 2 to solve for "N". It is this N that has been referred to as

ANFE above. These ANFE values were then deducted from the crop N fertilizer requirements based on realistic yield goal set for a specific field under consideration.

## RESULTS AND DISCUSSION:

Residual soil mineral-N measurements at planting and side dressing of grain sorghum are presented in Figure 4 for eight different sites in this study. Soil mineral-N levels at planting varied from 83 kg N ha<sup>-1</sup> in the Suffolk soil to 131 kg N ha<sup>-1</sup> in the Appling-Cecil complex, and from 72 kg N ha<sup>-1</sup> in the Suffolk soil to 197 kg N ha<sup>-1</sup> in the Atlee soil at side-dressing (Figure 4). For seven out of eight experimental soils, there was an increase in the level of soil mineral N from planting to side dressing (Table 4). The average increase was about 25% of the mineral-N at planting. This increase in the mineral-N occurred mainly in the surface horizon and probably came from the decomposition of organic matter. (Results of the chemical analysis of soils including organic matter are presented in Appendix C). Also, movement of mineral-N to deeper horizons (0.6 - 0.9 m) is evident on three soils (Figure 4). This pattern of downward movement of mineral-N over time indicates that leaching is probably a primary mechanism of N loss from rooting zone on these soils. Although downward movement of mineral-N occurred in three soils, however, that mineral-N would still be accessible to sorghum roots during later part of the growing season. About 99% of grain sorghum roots grow within the surface 0.9 m of soil (Bennett et al., 1990). Soil mineral-N measured to the surface 0.9 m of soil was >105 kg N ha<sup>-1</sup> for 7 out of 8 experimental soils in this study and would be expected to supply a substantial portion of N needed by the crop.

Climatic conditions in 1995 and 1997 were hot and dry, the rainfall distribution was erratic, and much below normal (Table 5). On-site precipitation data presented in Table 5 shows that the crop received only 361 mm of rainfall in 1995 and an average 230 mm of rainfall in 1997, much below the crop water requirement of 425 mm (Khosla and Persaud, 1997). Grain yields in 1995 and 1997 were limited by available soil moisture and did not respond to applied N (the difference between the check yield



**Figure 4. Soil mineral-N (nitrate + ammonium) measured at planting and side-dressing of grain sorghum for eight soils utilized for measuring grain sorghum response to N fertilization.**

**Table 4. Percent change in the soil profile residual mineral-N between planting and side-dressing of grain sorghum during three years in this study.**

Year	Soil types	Residual mineral-N		Percent change
		At planting	At side-dressing	
		----- kg ha <sup>-1</sup> -----		%
1995	<sup>1</sup> Pamunkey sl	70	106	51
1995	<sup>1</sup> Conetoe ls	66	94	42
1996	<sup>2</sup> Suffolk fsl	83	68	-18
1996	<sup>2</sup> Bojac sl	107	125	17
1996	<sup>2</sup> Appling-Cecil	131	137	5
1996	<sup>2</sup> Wheeling sl	114	143	25
1997	<sup>3</sup> Atlee vfl	129	197	53
1997	<sup>3</sup> Kempsville fls	87	118	36
<b>Mean</b>		<b>98</b>	<b>123</b>	<b>26</b>

<sup>1</sup>Soil depth 0-0.3m

<sup>2</sup>Soil depth 0-0.9m

<sup>3</sup>Soil depth 0-0.1.2m

Table 5. On site precipitation data for the study sites in 1995, 1996 and 1997, and 30 year average precipitation data for coastal Virginia.

Month	- Year 1995 -	-----Year 1996* -----			----- Year 1997 -----		30 Year Average
	----- Soil Types -----						
	Pamunkey sl & Conetoe ls	Suffolk fsl	Bojac sl	Appling-Cecil Complex	Atlee vfsl	Kempsville fls	
----- mm -----							
May	105	150	123	89	28	34	87
June	114	171	109	86	45	42	89
July	103	143	139	137	135	138	143
August	51	99	97	98	31	48	129
September	86	130	148	189	37	24	91
<b>Total</b>	<b>459</b>	<b>693</b>	<b>616</b>	<b>599</b>	<b>276</b>	<b>286</b>	<b>539</b>
Crop received	361	607	530	517	203	260	

\* On site data for Wheeling sl is not available, total rainfall was normal.

and the maximum yield was  $<1 \text{ Mg ha}^{-1}$ ). The grain yield data from the four non-responsive experimental sites in 1995 and 1997 were therefore excluded while examining the effects of residual soil mineral-N (Figure 4). In 1996, the total precipitation was normal to above average for most of the crop-growing season (Table 5). Grain yields responded positively to N fertilization (yield response  $>1 \text{ Mg ha}^{-1}$ ) on all four 1996 sites. Grain yields on the four responsive sites in 1996, varied from  $4.16 \text{ Mg ha}^{-1}$  to  $11.57 \text{ Mg ha}^{-1}$  (Appendix I).

Grain yield was regressed against N fertilizer rate and "yield increase to N fertilization" calculated as the yield difference between yield with zero N fertilizer and the highest yield on the regression curve (Scharf and Alley, 1994). The yield increase due to applied N ranged from  $2.03$  to  $4.92 \text{ Mg ha}^{-1}$  and was inversely correlated with residual soil mineral-N measured to a soil depth of  $0.9\text{m}$  at planting (Figure 5). The grain yield response to applied N decreases steeply with increasing residual soil mineral-N (Figure 5). Such strong negative correlation ( $r^2 = 0.94$ ) greatly supports our hypothesis that residual soil mineral-N does contribute to the N needs of the crop, and probably that soil mineral-N is not as transient during the growing season as it is generally assumed in the humid mid-Atlantic region. This is logical in the light of the relatively high check yields of  $4.16$ ,  $5.0$ ,  $6.12$ , and  $6.95 \text{ Mg}$  of grain yields  $\text{ha}^{-1}$ , produced on the Suffolk, Wheeling, Bojac, and Appling-Cecil soils, respectively. Nitrogen sufficient to produce these yields was supplied by the soil, mainly from residual soil mineral-N judging from the high levels observed in this study.

A major challenge with residual soil mineral-N is in equating the soil mineral-N values to a quantity of N fertilizer. The availability of residual soil mineral-N to plants depends on several variables such as soil type, organic matter content, temperature, precipitation, plant rooting depth and accessibility of mineral-N to roots, and various other bio-chemical processes occurring in soil. Therefore, the presence of

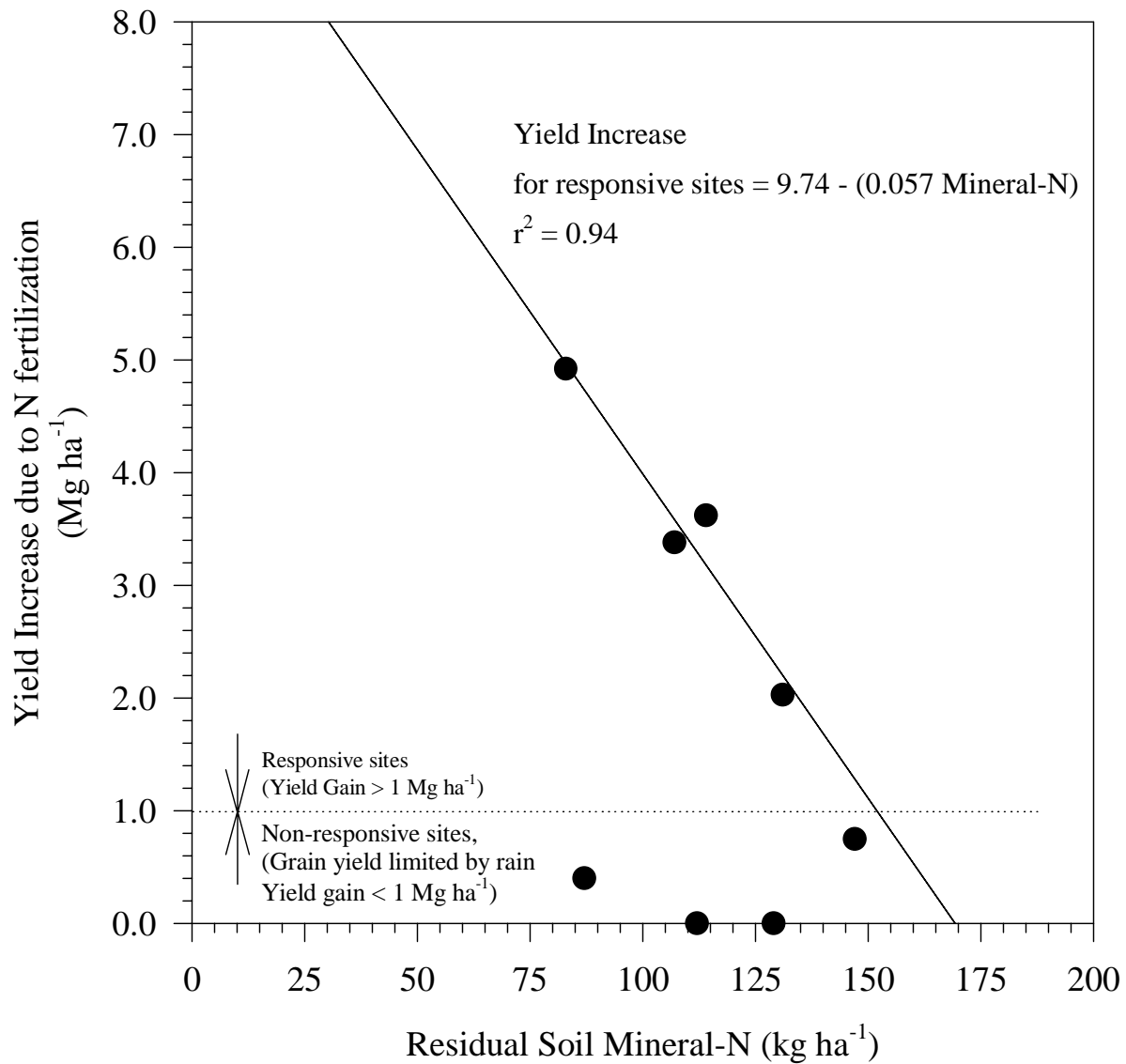


Figure 5. Sorghum grain yield increase due to N fertilizer application as a function of residual soil mineral N measured to 0.9m depth at planting.

Regression line is for responsive sites only

100 kg of residual mineral-N ha<sup>-1</sup> in soil does not necessarily translate into a fertilizer value of 100 kg N ha<sup>-1</sup> in terms of crop response. However, even if these above-mentioned variables are known, the contribution of soil mineral-N is often masked by the additional N fertilizer applications.

Figure 6a shows the relationship between the residual soil mineral-N and relative yield for the four responsive sites in this study. Relative yields in Figure 6a are the check plot yields with zero N fertilizer calculated as the percent of maximum yield for each particular site. Figure 6b presents the relationship between applied N and relative yield for the four responsive soils in this study. Traditionally, relative yield would be calculated as the grain yield for each treatment divided by the maximum yield for that site and expressed as the percent of maximum yield (Piekielek and Fox, 1992; Evanylo and Alley, 1997). However, such an estimation of the relative yield would also include the contribution of residual soil mineral-N to grain yield from each treatment. Therefore, to remove the effect of soil mineral-N, relative yield in Figure 6b was calculated as the grain yield for each treatment minus the check yield with zero N fertilizer. The yield due to N fertilizer applications was then expressed as percent of the maximum yield after subtracting the check yield from the maximum yield. Such estimation eliminated the contribution of soil mineral-N in grain yield and the response function thus developed is the estimate of grain yield response solely due to applied N on the same soils with no mineral-N (Figure 6b). The response function thus developed also ranges from zero through 100 percent, as opposed to a higher starting level due to the check yield.

The response functions generated in Figure 6a and 6b are referred to as Equation 1 and Equation 2, respectively. In order to estimate the Associated N Fertilizer Equivalent (ANFE) value of soil mineral-N, the range of soil mineral-N values observed in these experiments were substituted in the first response function, Equation 1, to calculate the relative yield values. These relative yield values were then substituted in

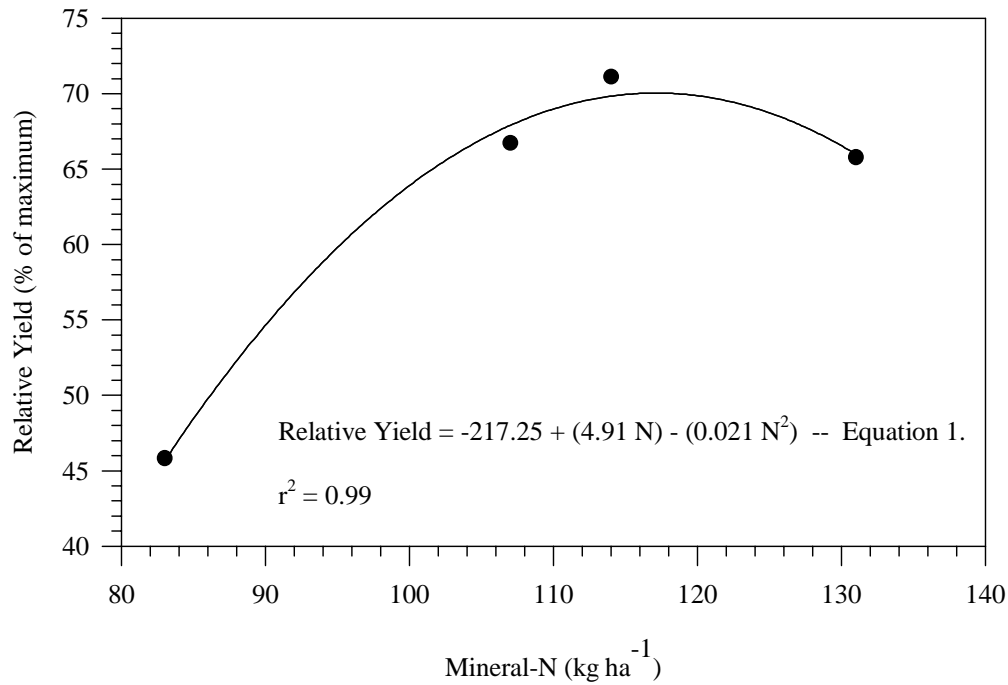


Figure 6a. Relationship between soil profile (0-0.9m) residual mineral-N sampled at planting and relative yield of four responsive sites in this study. Each data point is the grain yield in check plot treatment presented as % of maximum grain yield.

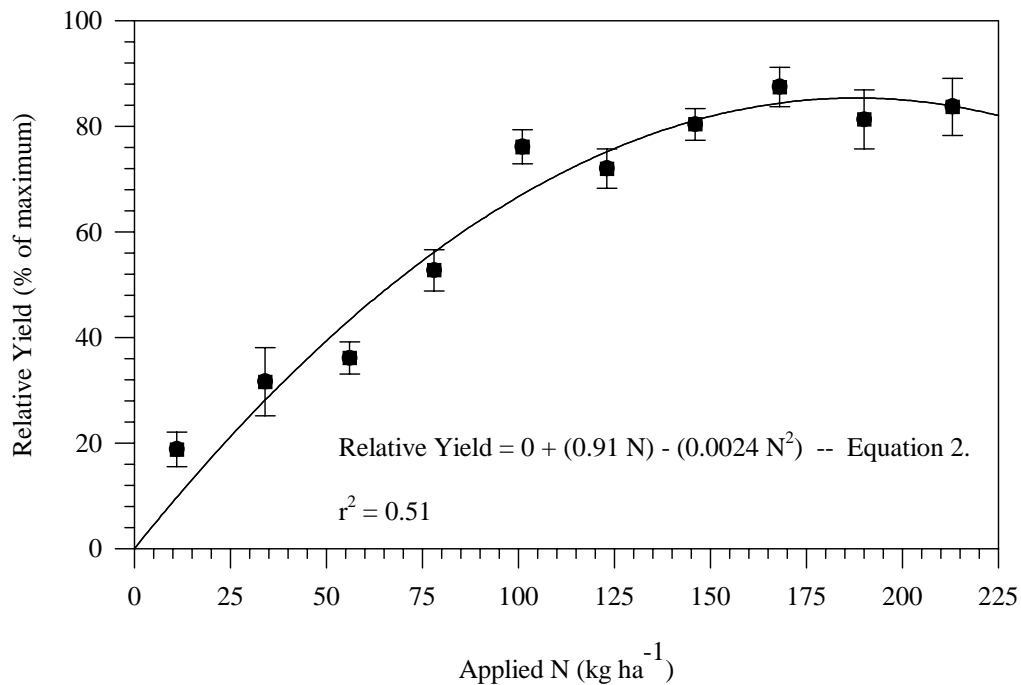


Figure 6b. Relationship between relative yield in response to various rates of applied N on four responsive sites in this study. Each data point is a mean of 32 data points. Error bars are the standard error of the means.

the second response function, Equation 2, and solved for N. The N rates ( $\text{kg ha}^{-1}$ ) thus calculated are the amounts of applied N that have the potential to produce the same yield as that produced by the residual soil mineral-N, and is defined as “Associated Nitrogen Fertilizer Equivalent” (ANFE). Therefore, based on the measured soil mineral-N level at planting, ANFE values can be calculated and deducted from the total crop N requirement that is based on a field specific yield goal. Table 6 shows the ANFE values calculated for the range of soil mineral-N values observed in these experiments.

In order to test the validity of the estimated ANFE values, the crop N requirement was calculated as the total N-uptake or removal by grain and stover (Table 6). The ANFE values were then subtracted from the crop N requirement to estimate the N fertilizer recommendations based on ANFE. The resulting N fertilizer rates were quite close for two (Suffolk and Bojac soil sites) out of four experimental sites as compared to the N rates at which the maximum yields were obtained in this study (Table 6). The ANFE system over (Appling-Cecil complex) and under (Wheeling) predicted the required N rates for one site each. This perhaps may be attributed to the variability of N supply from other sources that are not accounted for in Equation 2 (Figure 6b). The  $r^2$  value for Equation 2 is 0.51, suggesting the contribution of other factors in the relationship between applied N and relative yield, such as climate, fluctuations in the soil mineral-N levels during the growing season, and the efficiency of applied N. This study did not monitor the contribution of mineral-N to soil by other bio-chemical processes and sources present in soil. Monitoring the contribution of other sources of mineral-N may be helpful in identifying the soil mineral-N levels at various growth stages of the crop during the growing season. It should also be noted that the data used in developing the relationship between applied N and relative yield were data from only four responsive sites in a single cropping year, out of eight experimental sites in this study. Figure 6 indicates that soil mineral-N levels on these four sites were not high enough to achieve 100 percent of the maximum yield. The soil mineral-N levels produced only

**Table 6. Soil types, observed grain yield, residual soil mineral-N measured to 0.9m soil depth at planting, relative yield, calculated associated nitrogen fertilizer equivalency (ANFE), N-uptake by the crop, N treatment rates applied to achieve the highest grain yield, N recommendations based on yield goal, and the N fertilizer recommendation based on ANFE concept for the four responsive sites in this study.**

Soil type	Highest grain yield	Soil mineral-N	Relative yield <sup>1</sup>	Associated N Equivalency <sup>2</sup>	N-Uptake	N applied as treatment	N-recommendation based on yield goal <sup>3</sup>	N recommendation based on ANFE
	Mg ha <sup>-1</sup>	kg ha <sup>-1</sup>	%	-----		kg ha <sup>-1</sup>	-----	
Suffolk fsl	9.08	83	46	60	210	173	195	150
Bojac sl	9.17	107	68	102	258	135	197	156
Appling-Cecil	10.57	131	66	98	270	106	227	173
Wheeling sl	7.03	114	69	107	187	129	151	79

<sup>1</sup>Relative yield calculated from equation 1: Relative yield = -217.25 + (4.91 N) - (0.021 N<sup>2</sup>)

<sup>2</sup>Associated Nitrogen Equivalency calculated from equation 2: Relative yield = 0 + (0.91 N) - (0.0024 N<sup>2</sup>)

<sup>3</sup>(23.21 kg per Mg of grain yield) Adapted from Virginia nutrient management standards and criteria, 1995.

77 percent of the maximum yield among the four responsive sites (Figure 6). Still the ANFE fertilizer recommendation rates were 41 and 45 kg ha<sup>-1</sup> more efficient as compared to the traditional method of N fertilizer recommendation based on yield goal (Table 6).

Although the ANFE concept could not accurately predict the N fertilizer rates for all the soils, the findings are encouraging especially when it is based on only four different soils in a single cropping year. More research is needed on several different sites with varying levels of residual soil mineral-N to develop a stronger relationship between soil mineral-N and the ANFE. Development of the ANFE concept has potential to include soil mineral-N as an integral part of the fertilizer N recommendation system on a field specific basis in the humid mid-Atlantic region.

## CONCLUSIONS

Soil mineral-N levels varied from 83 to 131 kg N ha<sup>-1</sup> at planting in these experiments. These levels of soil mineral-N are high enough to have substantial effects on the N fertilizer requirement of the grain sorghum crop. Grain yields responded positively to N fertilization on four soils in 1996 when adequate moisture was available for crop growth. The grain yield increase due to applied N ranged from 2.03 to 4.92 Mg ha<sup>-1</sup> and was inversely correlated with residual soil mineral-N measured to a soil depth of 0.9m at planting. Such strong negative correlation ( $r^2 = 0.94$ ) greatly supported our hypothesis that residual soil mineral-N does contribute to the N needs of the crop, and probably that soil mineral-N is not as transient as it is generally assumed in the humid mid-Atlantic region.

The N fertilizer recommendations based on ANFE values were quite close for two out of four sites as compared to the N rates at which the maximum yields were obtained in this study. The ANFE fertilizer recommendation rates were 41 and 45 kg ha<sup>-1</sup> more efficient as compared to the traditional method of N fertilizer recommendation based on yield goal. More research is needed on several different sites with varying level of residual soil mineral-N to develop a stronger relationship between soil mineral-N and the ANFE. The finding suggests that ANFE concept has potential to consider soil mineral-N as an integral part of the fertilizer N recommendation system in the humid mid-Atlantic region.

## REFERENCES:

Alley, M.M., P. Scharf, D.E. Brann, W.E. Baethgen, and S.J. Donohue. 1989. Efficient N fertilization of winter wheat: principles and recommendations. Virginia Cooperative Extension Publication 424-026.

Alley, M.M., R. Khosla, P.H. Davis, and D.E. Brann. 1996. Rate and placement of nitrogen and phosphorus fertilizer for efficient and environmentally sensitive grain sorghum. *In* 1996 Fluid Fertilizer Foundation Fluid Forum Proceedings. Scottsdale, AZ.

Bennett, W.F., B.B. Tucker, and A.B. Maunder. 1990. Modern Grain Sorghum Production. p.109. Iowa State University Press, Ames IA.

Blackmer, A.M., D. Pottker, M.E. Cerrato, and J. Webb. 1989. Correlations between soil nitrate concentrations in late spring and corn yields in Iowa. *J. Prod. Agric.* 2:103-109.

Bundy, L.G. and E.S. Malone. 1988. Effect of residual nitrate on corn response to applied nitrogen. *Soil Sci. Soc. Am. J.* 52:1377-1383.

Evanylo, G.K. and M.M. Alley. 1997. Presidedress soil nitrogen test for corn in Virginia. *Commun. Soil Sci. Plant Anal.*, 28: 1285-1301.

Fox, R.H., and W.P. Piekielek. 1984. Relationships among anaerobically mineralized nitrogen, chemical indexes, and nitrogen availability to corn. *Soil Sci. Soc. Am. J.* 48:1087-1090.

Fox, R.H., G.W. Roth, K.V. Iversen, and W.P. Piekielek. 1989. Soil and tissue nitrate tests compared for predicting soil nitrogen availability to corn. *Agron. J.* 81:971-974.

Gilliam, J.W., and F. Boswell. 1984. Management of nitrogen in the South Atlantic states. p.691-705. *In* R.D. Hauck (ed.) Nitrogen in crop production. ASA, Madison, WI.

Hanway, J., and L. Dumenil. 1955. Predicting nitrogen fertilizer needs of Iowa soils: III. Use of nitrate production together with other information as a basis for making nitrogen fertilizer recommendations for corn in Iowa. *Soil Sci. Soc. Proc. Am.* 19:77-80.

Hergert, G.W. 1987. Status of residual nitrate-nitrogen soil tests in the United States of America p.73-88. *In* J.R. Brown Soil testing: sampling, correlation, calibration, and interpretation. SSSA Special publication Number 21. Soil Sci. Soc. Am., Inc. Madison, WI.

Iversen, K.V., R.H. Fox, and W.P. Piekielek. 1985. The relationships of nitrate concentrations in young corn stalks to soil nitrogen availability and grain yields. *Agron. J.* 77:927-932.

Jolley, V.D., and W.H. Pierre. 1977. Profile accumulation of fertilizer derived nitrate and total nitrogen recovery in two long term nitrogen rate experiments with corn. *Soil Sci. Soc. Am. J.* 41:373-378.

Keeney, D.R. 1982. Nitrogen-availability indexes. *In* A.L. Page, R.H. Miller, and D.R. Keeney (ed.) *Methods of soil analysis. Part 2.* 2nd ed. *Agronomy* 9:711-733.

Keeney, D.R., and D.W. Nelson. 1982. Nitrogen-inorganic forms. *In* A.L. Page, R.H. Miller, and D.R. Keeney (ed.) *Methods of soil analysis. Part 2.* 2nd ed. *Agronomy* 9:643-698.

Khosla, R. and N. Persaud. 1997. Performance of a non-nuclear resonant frequency capacitance probe. II. Measurement of dryland crop water use. *Commun. Soil Sci. plant Anal.*, 28: 1347-1357.

Kitur, B.K., M.L. Smith, R.L. Blevins, and W.W. Frye. 1984. Fate of <sup>15</sup>N-depleted ammonium nitrate applied to no-tillage and conventional tillage corn. *Agron. J.* 76:240-242.

Magdoff, F.R., D. Ross, and J. Amadon. 1984. A soil test for nitrogen availability to corn. *Soil Sci. Soc. Am. J.* 48:1301-1304.

Meisinger, J.J. 1984. Evaluating plant-available nitrogen in soil-crop systems. p. 391-416. *In* R.D. Hauck (ed.) *Nitrogen in crop production.* ASA, Madison, WI.

Meisinger, J.J., R.F. Mulford, and J.S. Stangarone. 1987. Effects of residual N on winter wheat in Maryland. p.209. *In* *Agronomy Abstracts.* ASA, Madison, WI.

Onken, A.B. R.L. Matheson, and D.M. Nesmith. 1985. Fertilizer nitrogen and residual nitrate-nitrogen effects on irrigated corn yield. *Soil Sci. Soc. Am. J.* 49:134-139.

Piekielek, W.L., and R.H. Fox. 1992. Use of chlorophyll meter to predict sidedress nitrogen requirements for maize. *Agron. J.* 84:59-65.

Pierre, W.H., L. Dumenil, and J. Henao. 1977. Relationship between corn yield, expressed as a percentage of maximum, and the N percentage in the grain. II. Diagnostic Use. *Agron. J.* 69:221-226.

- Power, J.F., J.W. Doran, and W.W. Wilhelm. 1986. Uptake of nitrogen from soil, fertilizer, and crop residues by no-till corn and soybean. *Soil Sci. Soc. Am. J.* 50:137-142.
- Roberts, S., W.H. Weaver, and J.P. Phelps. 1980. Use of the nitrate soil test to predict sweet corn response to nitrogen fertilization. *Soil Sci. Soc. Am. J.* 44:306-308.
- SAS Institute. 1993. SAS user's guide. SAS Institute Inc., Cary, North Carolina, USA.
- Scharf, P.C. 1993. Development of field-specific spring N rate recommendations for winter wheat. Ph.D. dissertation. Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.
- Scharf, P.C., and M.M. Alley. 1994. Residual soil nitrogen in humid region wheat production. *J. Prod. Agric.* 7:81-85.
- Stanford, G. 1982. Assessment of soil nitrogen availability. *In* F.J. Stevenson (ed.) *Nitrogen in agricultural soils.* *Agronomy* 22:651-688.
- Timmons, D.R., and R.M. Cruse. 1990. Effect of fertilization method and tillage on nitrogen-15 recovery by corn. *Agron. J.* 82:777-784.
- Timmons, D.R., and R.M. Cruse. 1991. Residual nitrogen-15 recovery by corn as influenced by tillage and fertilization method. *Agron. J.* 83:357-363.
- Virginia Nutrient Management Standards and Criteria. 1995. Department of Conservation and Recreation, Division of Soil and Water Conservation, 203 Governor Street, Suite 206, Richmond, VA 23219-2094.
- Vanderlip, R.L. 1993. How a sorghum plant develops. Cooperative extension service. Contribution No. 1203, Kansas Agricultural Experiment Station, Manhattan, Kansas.
- Voss, Regis D. 1982. General guide for fertilizer recommendations in Iowa. AG-65 (Rev). Iowa State University Cooperative Extension Service. Ames, IA.