

Influence of residual profile mineral-N on sorghum response to applied N at Samaru, Nigeria

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Abstract

Contribution of residual profile mineral-N to crop response is often neglected when making fertiliser recommendations due to the still widely accepted perception that mineralisation ceases during harmattan in the northern Guinea Savanna of Nigeria. Consequently, this study was to examine the effect of soil mineral-N on sorghum response to N fertilisation with neem seed cake (NSC) and inorganic fertilizer, and to determine if soil mineral-N can be considered as a part of an N fertilizer recommendation program in this region for the complementary use of NSC. The experiment was laid down in a complete randomised design with three replicates. Soil mineral-N varied from 0.010 to 0.024 kg ha⁻¹ at planting and from 0.007 to 0.013 kg ha⁻¹ at side dressing and contributed substantially to the needs of the grain sorghum crop. The grain yield due to applied N ranged from 0.0019 to 0.0839kg ha⁻¹ and was inversely correlated with the residual soil mineral-N measured to a depth of 0.15m at planting. The ANFE fertiliser recommendation rates were about 90% more efficient as compared to the traditional method of N fertiliser recommendation based on yield goal. However, more research is needed using a lower depth (0.9 to 0.12m) considering the scavenging nature of sorghum; also several different sites with varying levels of residual mineral-N should be used 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 fertiliser N recommendation system in the region.

Keywords: Associated nitrogen fertiliser equivalency, inorganic fertiliser, mineral-N, neem seed cake, residual.

Introduction

Potentials of locally available organic wastes as soil amendments are attracting researchers' concern (Mohammed *et al.*, 2014). Thus, the choice of neem seed cake used in the present study among other amendments which have shown varying degrees of influence on the fertility status of the soil (Mohammed *et al.*, 2015). The contribution of residual profile mineral-N to crop response is often neglected when making fertilizer recommendation at Samaru in the Northern Guinea Savanna of Nigeria. This neglect appears to be, in part, due to the still widely accepted perception that mineralisation ceases during harmattan, and soil mineral-N losses are high in this region through leaching and denitrification during the rainy season. Nitrogen (N) fertilisation in this region in particular, is more critical than for any other region in Nigeria because soils are well drained, fine loamy, kaolinitic with low organic matter content (0.44%) 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 fertilisation. However, increased environmental concerns in the last two decades and the erratic rainfall pattern in the region recently 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 fertilisation in the northern Guinea Savanna is not widely acknowledged because of the widely held perception that high intensity 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 fertilisation (Keeney, 1982; Stanford, 1982; Magdoff *et al.*, 1984; Iversen *et al.*, 1985). However, none of these procedures have been widely adopted in this region. The N fertiliser 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). 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 neither his none 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. A systematic approach for interpreting residual soil profile mineral-N value is needed in the savanna regions that eliminate the practice or uncertainty of equating soil-N test results to a quantity of N fertiliser. A mechanism that accounts for soil mineral-N when making fertiliser 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 northern Guinea savanna 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 fertilisation from neem seed cake and/ or inorganic fertiliser; to determine if agronomically significant levels of residual mineral-N exist in fields used for grain sorghum production in rotation with cowpea; and to consider a system that could account for soil mineral-N in making N fertiliser recommendations for grain sorghum production in Samaru.

Materials and method

Field study was conducted to determine the effects of residual profile mineral-N on sorghum yield response to applied N at the experimental field of the Institute for Agricultural Research in Samaru-Zaria during the 2009 and 2010 cropping season since initial physico-chemical properties of the soil were low, implying a good response to applied nutrients (Data presented elsewhere). The site was characterised by sandy loam, with low available water holding capacity and <0.5% organic carbon (Mohammed *et al.*, 2014). Soil samples for mineral-N were collected prior to planting in the month of May and then 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 an auger to a depth of 0.15 m. These samples were distilled off without any prior preparation with magnesium oxide for $\text{NH}_4\text{-N}$ followed by addition of devarda alloy to the same sample for $\text{NO}_3\text{-N}$, respective distillates were collected over 10 ml 20% boric acid determined titrimetrically with 0.025N H_2SO_4 . Soil nitrate and ammonium contents were calculated (dry weight basis) as kg ha^{-1} based on the analysed soil bulk density for the initial composited bulk sample for the site.

Urea (46% N) pellets were used as a source of inorganic fertiliser N while neem seed cake (3.85% and 5.33% N in 2009 and 2010) was used as an organic N source (Data presented elsewhere; Mohammed *et al.*, 2014). Treatments consisted of factorial combinations of four rates of inorganic N-fertiliser applications applied in two split doses, and four levels of NSC incorporated two weeks before planting as a single dose to supply a total of sixteen different N fertilisation rates of 0, 16, 32, 38.5, 54.5, 64, 70.5, 77, 93, 102.5, 109, 141, 154, 170, 186 and 218 kg N ha^{-1} in 2009 and 0, 16, 32, 53.4, 59.4, 64, 85.4, 106.8. Experimental design was a randomised complete block with three replicates. Each plot consisted of six 0.15 m wide rows, 6 m in length. Sorghum grain yield and soil samples from 0 to 15 cm depth for mineral-N were obtained from the four middle rows (net plot) of each plot

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 fertiliser 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 fertiliser 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 fertiliser requirements based on realistic yield goal set for a specific field under consideration.

Results and discussion

There was no significant difference in residual soil mineral-N with treatments at planting in both years (Table 1). In 2009, there was a decrease in the level of soil mineral N from planting to side dressing for fifteen out of the sixteen treatments (Table 2). The average decrease was about 65% of the mineral-N at planting. This decrease in the mineral-N at the surface horizon (0 – 15 cm) probably was as a result of leaching of the mineral-N to a lower depth which was not considered in this study for the inorganic fertiliser plots. Also, the erratic rainfall patterns recorded in this year could account for the decrease observed in the inorganic soil amendments plots at side dressing. However, for the NSC-amended plots, the decrease observed in the mineral-N of the soil could be attributed to the initial N flush as a result of micro-organisms which increased the mineral-N at planting due to decomposition of organic matter (Agbenin *et al.*, 1999). In 2010, for all the sixteen treatments, there was a decrease in the level of soil mineral N from planting to side dressing. The average decrease was about 37% of the mineral N at planting. This decrease could be attributed to the continuous mining of nutrients from the soil from the same depth owing to the monocropping farming system in the study (sorghum following sorghum) as well as leaching losses.

Grain yield was regressed against N fertiliser rate and "yield increase to N fertilisation" calculated as the yield difference between yield with zero N fertiliser and the highest yield on the regression curve (Scharf and Alley, 1994). The yield increase due to applied N in 2009 ranged from 0.0019 to 0.0839 kg ha⁻¹ and was inversely correlated with residual soil mineral-N measured to a soil depth of 0.15m at planting (Table 3). The grain yield response to applied N decreases gently with increasing residual soil mineral-N (Figure 1). Such positive correlation ($r^2 = 0.3877$) 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 northern guinea savanna region of Nigeria. This is logical in the light of the relatively high check yields of 0.2017 kg of grain yields ha^{-1} , produced on the control (zero NSC and inorganic fertilizer) plots. 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. This corroborates with the submission of Khosla *et al.* (2000) on nitrogen response in grain sorghum production.

In 2010, the yield increase due to applied N ranged from -0.0647% to -2.4878% and was negligibly correlated ($r = 0.01$) with residual soil mineral-N measured to a depth of 0 to 15 cm at planting (Table 4). The grain yield response to applied N decreased gently with increasing residual soil mineral-N (Figure 2). The relatively negligible correlation ($r^2 = 0.0001$) observed in 2010 still supports the hypothesis that residual soil mineral-N does contribute to the needs of the crop. The trend could however be attributed to one of the challenges of equating residual soil mineral-N to a quantity of fertilizer (Li *et al.*, 2009).

A major challenge with residual soil mineral-N is in equating the soil mineral-N values to a quantity of N fertiliser. 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 100 kg of residual mineral-N ha^{-1} in soil does not necessarily translate into a fertiliser value of 100 kg N ha^{-1} in terms of crop response. However, even if these abovementioned variables are known, the contribution of soil mineral-N is often asked by the additional N fertiliser applications. High conventional fertiliser N and fluctuation in day and night temperature stimulate soil microbial community to produce soil mineral-N through increased degradation of organic matter (Liu *et al.*, 2015) which these microbes synthesize for their own use.

Figures 3, 4, 5 and 6 show the relationship between the residual soil mineral-N and relative yield for the responsive treatments in 2009 and 2010. Relative yields in Figures 3 and 5 are the check plot yields with zero N fertiliser calculated as the percent of maximum yield for each particular treatment. Figures 4 and 6 present the relationship between applied N and

relative yield for the ten responsive treatments in 2009 and 2010. 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 Figures 3 and 5 was calculated as the grain yield for each treatment minus the check yield with zero N fertilizer in 2009 and 2010 respectively. The yield due to N fertiliser applications was then expressed as a percentage 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 3 and 5). The response function thus developed also ranges from zero through 100 percent, as opposed to a higher starting level due to the check yield emanating from increased annualised production, reduced contribution of N mineralisation, and increased immobilisation and volatilization potential of surface-applied fertiliser N (Schlegel *et al.*, 2005).

The response functions generated in Figure 3 and 5 for 2009 and Figure 4 and 6 for 2010 are referred to as Equation 1 and Equation 2, respectively. In order to estimate the Associated N Fertiliser Equivalent (ANFE) value of soil mineral-N, the range of soil mineral-N values observed in these experiments was 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, and solved for N. The N rates (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 Fertiliser 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 3 and 4 shows the ANFE values calculated for the range of soil mineral-N values observed in this experiment in 2009 and 2010 respectively.

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 in 2009 and 2010 respectively (Table 3 and 4). The ANFE values were then subtracted from the crop N requirement to estimate the N fertiliser recommendations based on ANFE. The resulting N fertiliser rates were quite close for two (optimum recommended N rate and the full NPK rate plus 4 tonnes of NSC) out of sixteen treatment combinations as compared to the N rates at which the maximum yields were obtained in this study (Table 3 and 4). The ANFE system gave an approximate prediction of the required N rates for virtually all treatments with little variations. This perhaps may be attributed to the variability of N supply from other sources that are not accounted for in Equation 2 (Figure 5 and 6). The r^2 value for Equation 2 is 0.2425 and 0.0794 in 2009 and 2010 respectively, 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 responsive treatments in each single cropping year, out of sixteen experimental treatments in this study. Figure 5 and 6 indicate that soil mineral-N levels on the ten and fourteen treatment plots, respectively were not high enough to achieve 100 percent of the maximum yield. The soil mineral-N levels produced only 75.75 percent of the maximum yield among the ten treatment combinations (Figure 5 and 6). Still, the ANFE fertilizer recommendation rates were about 90 % more efficient as compared to the traditional method of N fertilizer recommendation based on yield goal (Table 2).

Although, the ANFE concept predicted the N fertiliser rates with little differences with r value of 0.66 (Figure 7) from that actually taken up by the plants, the findings are encouraging when they are based on only one soil receiving different treatments in a single cropping year. More research is however 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 fertiliser N recommendation system on a field specific basis in the northern Guinea Savanna of Nigeria.

Conclusion and recommendation

Soil mineral-N levels varied from 0.010 to 0.024 kg ha⁻¹ at planting in this experiment. These levels of soil mineral-N are high enough to have substantial effects on the N fertiliser requirement of the grain sorghum crop. Grain yields responded positively to N fertilisation in ten plots in 2009 when adequate moisture was available for crop growth. The grain yield increase due to applied N ranged from 0.0019 to 0.0839 kg ha⁻¹ and was inversely correlated with residual soil mineral-N measured to a soil depth of 0.15m at planting. Such positive correlation ($r^2 = 0.39$) 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 northern guinea savanna region. The N fertiliser recommendations based on ANFE values were quite close for all treatment combinations as compared to the N rates at which the maximum yields were obtained in this study. The ANFE fertiliser recommendation rates were about 90 % more efficient as compared to the traditional method of N fertiliser recommendation based on yield goal. 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 as well as a consideration of lower depth along the soil profile. The finding suggests that ANFE concept has potential to consider soil mineral-N as an integral part of the fertiliser N recommendation system in the northern guinea savanna region of Nigeria.

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Table 1: Mineral nitrogen at various growth stages of sorghum as affected by neem seed cake and inorganic fertilizer at Samaru in 2009 and 2010

Treatment	2009			2010		
	2 weeks before planting	At planting	At side-dressing	2 weeks before planting	At planting	At side-dressing
NPK kg ha ⁻¹ (N)						
0	0.04730	0.02640	0.01008	0.00788	0.02042	0.01378
¼ RR	0.04730	0.03021	0.00848	0.00802	0.01910	0.01291
½ RR	0.04730	0.02408	0.00862	0.00831	0.02144	0.01385
FRR	0.04730	0.02758	0.0104	0.00875	0.01998	0.01415
SE ±	2.47E-36	0.00007	0.000003	0.000002	0.00001	0.000002
NSC ton ha ⁻¹ (S)						
0	0.04730	0.02013	0.01038a	0.00788	0.01867	0.01283
1	0.04730	0.02772	0.00950ab	0.00758	0.01867	0.01458
2	0.04730	0.02831	0.00745b	0.00846	0.02217	0.01327
4	0.04730	0.03211	0.01023ab	0.00904	0.02144	0.01400
SE ±	2.47E-36	0.00007	0.000003	0.000002	0.00001	0.000002
Interaction (N × S)						
N × S						

NB: Mean different at p ≤ 0.05; NS = not significant

Legend: 0= control; ¼RR = quarter recommended NPK fertilizer rate; ½RR = half recommended NPK fertilizer rate; FRR= full NPK fertilizer rate

Table 2: Percent change in the surface soil residual mineral-N between planting and side dressing of grain sorghum in 2009 and 2010

Treatments	Residual mineral-N (%)					
	At Planting		At Side dressing		Percent change	
	2009	2010	2009	2010	2009	2010
0/0	0.0105	0.0175	0.0111	0.0117	6.05	-33.33
0/¼	0.0251	0.0163	0.0088	0.0123	-65.07	-25.00
0/½	0.0228	0.0222	0.0111	0.0125	-51.24	-43.42
0/FULL	0.0222	0.0187	0.0105	0.0149	-52.55	-20.31
1/-0	0.0286	0.0228	0.0111	0.0155	-61.19	-32.05
1/¼	0.0333	0.0152	0.0088	0.0140	-73.65	-7.69
1/½	0.0198	0.0175	0.0076	0.0166	-61.68	-5.00
1/FULL	0.0292	0.0193	0.0105	0.01225	-63.89	-36.36
2/-0	0.0368	0.0204	0.0082	0.0146	-77.70	-28.57
2/¼	0.0245	0.0216	0.0070	0.0120	-71.47	-44.59
2/½	0.0222	0.0228	0.0076	0.0128	-65.71	-43.59
2/FULL	0.0298	0.0239	0.0070	0.0137	-76.48	-42.68
4/-0	0.0298	0.0210	0.0099	0.0134	-66.63	-36.11
4/¼	0.0379	0.0222	0.0094	0.0137	-75.31	-38.16
4/½	0.0315	0.0233	0.0082	0.0134	-74.10	-42.50
4/FULL	0.0292	0.0181	0.0134	0.01575	-54.00	-12.90

Legend: 0/0= control; 0/¼ = 0 neem seed cake plus quarter recommended NPK fertilizer rate; 0/½ = zero neem seed cake plus half recommended NPK fertilizer rate; 0/FULL = zero neem seed cake plus full recommended NPK fertilizer; 1/-0 =one tonne per hectare neem seed cake plus zero NPK fertilizer; 1/¼ = one tonne per hectare neem seed cake plus quarter recommended NPK fertilizer rate; 1/½ = one tonne per hectare neem seed cake plus half recommended NPK fertilizer rate; 1/FULL = one tonne per hectare neem seed cake plus full recommended NPK fertilizer rate; 2/0 = two tonnes per hectare neem seed cake plus zero NPK fertilizer; 2/¼ = two tonnes per hectare neem seed cake plus quarter recommended NPK fertilizer rate; 2/½ = two tonnes per hectare neem seed cake plus half recommended NPK fertilizer rate; 2/FULL = two tonnes per hectare neem seed cake plus full recommended NPK fertilizer rate; 4/0= four tonnes per hectare neem seed cake plus zero NPK fertilizer; 4/¼ = four tonnes per hectare neem seed cake plus quarter recommended NPK fertilizer rate; 4/½ = four tonnes per hectare neem seed cake plus half recommended NPK fertilizer rate; 4/FULL = four tonnes per hectare neem seed cake plus full recommended NPK fertilizer rate

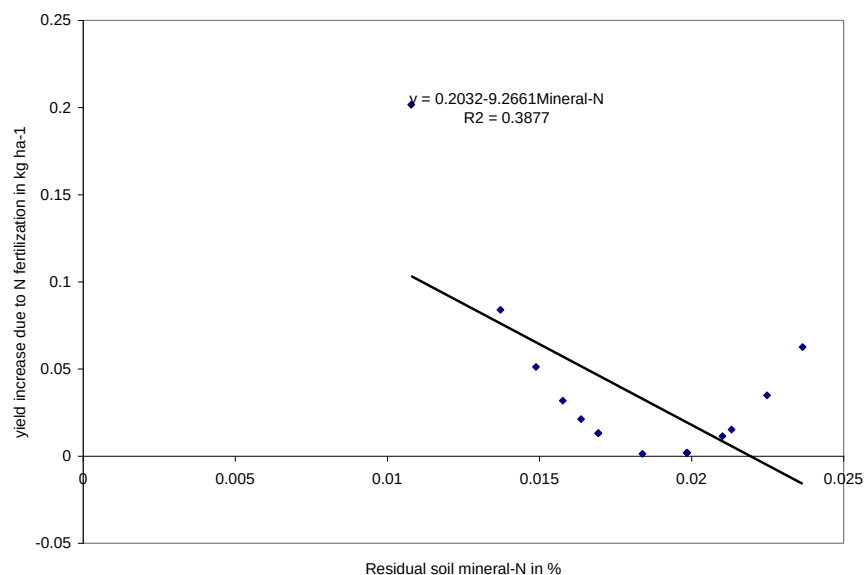


Figure 1: Sorghum grain yield increase due to NSC and inorganic fertiliser application as a function of residual soil mineral-N measured at 0-15cm depth at planting in 2009

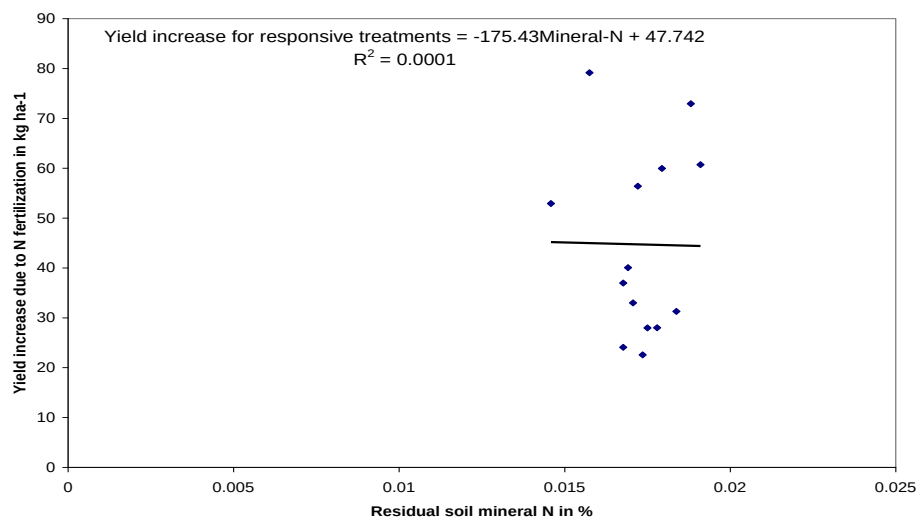


Figure 2: Sorghum grain yield increase due to N fertiliser application as a function of residual mineral N (0-15cm depth) at planting in 2010

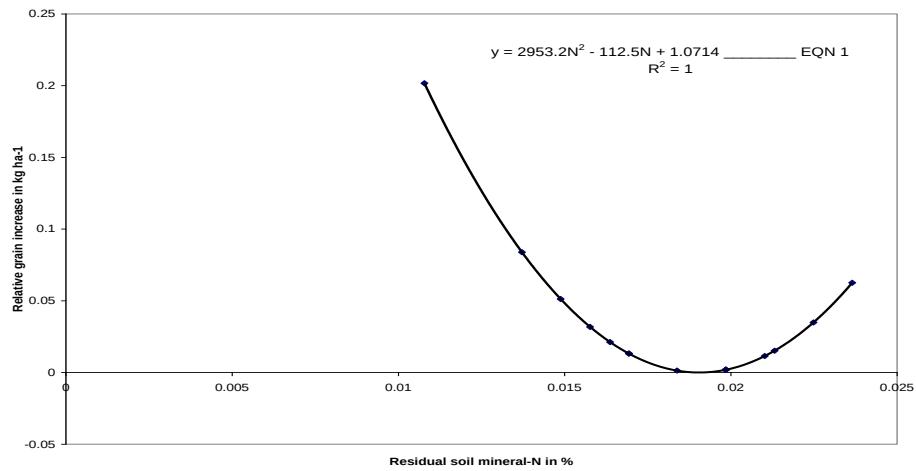
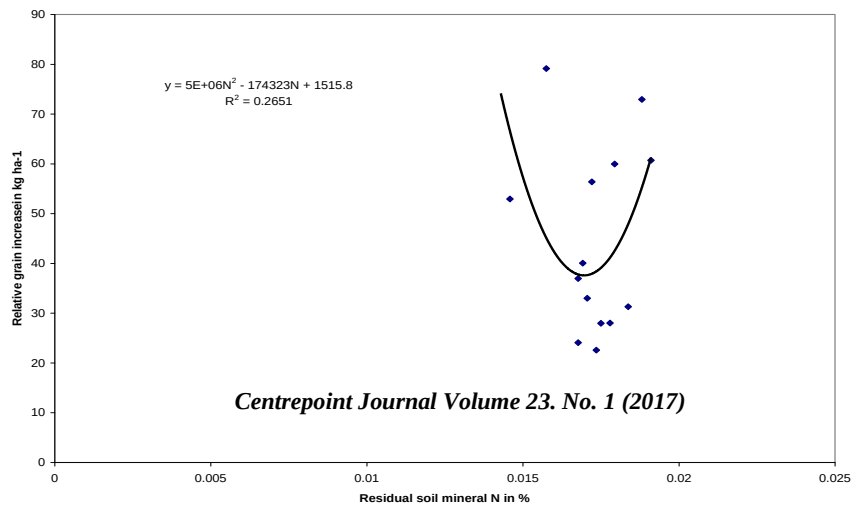


Figure 3: Relative yield at various levels of mineral-N in 2009



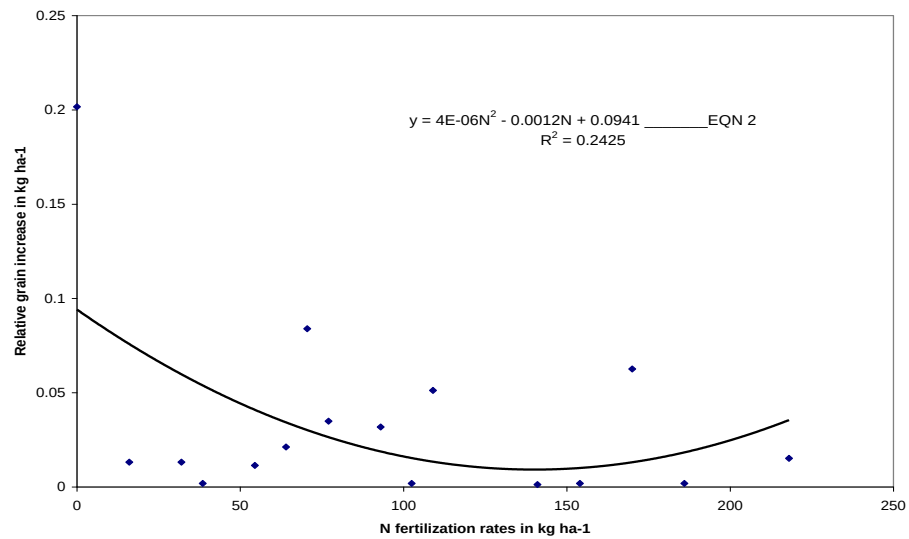


Figure 5: Relative grain yield as a function of various rates of N fertilisation in 2009

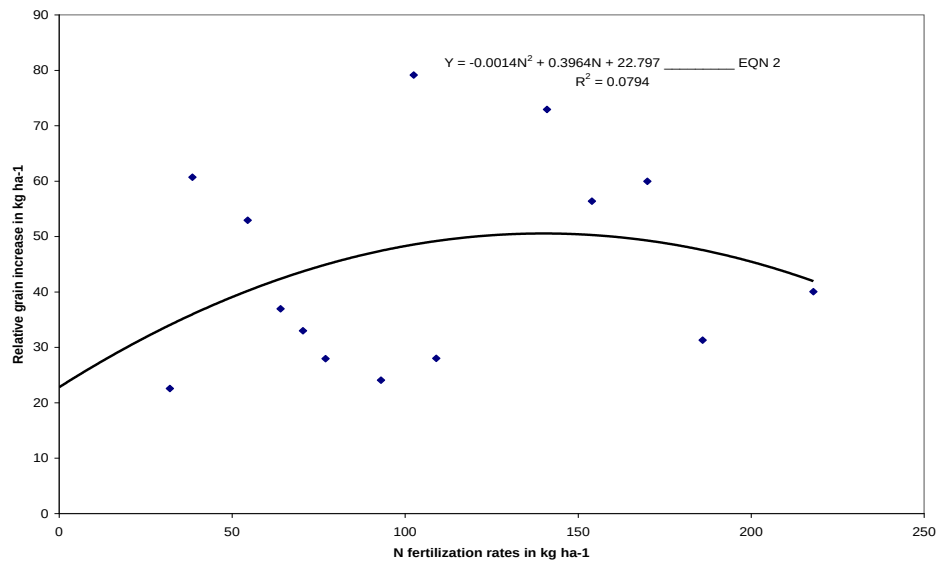


Figure 6: Relative grain yield as a function of various rates of N fertilisation in 2010

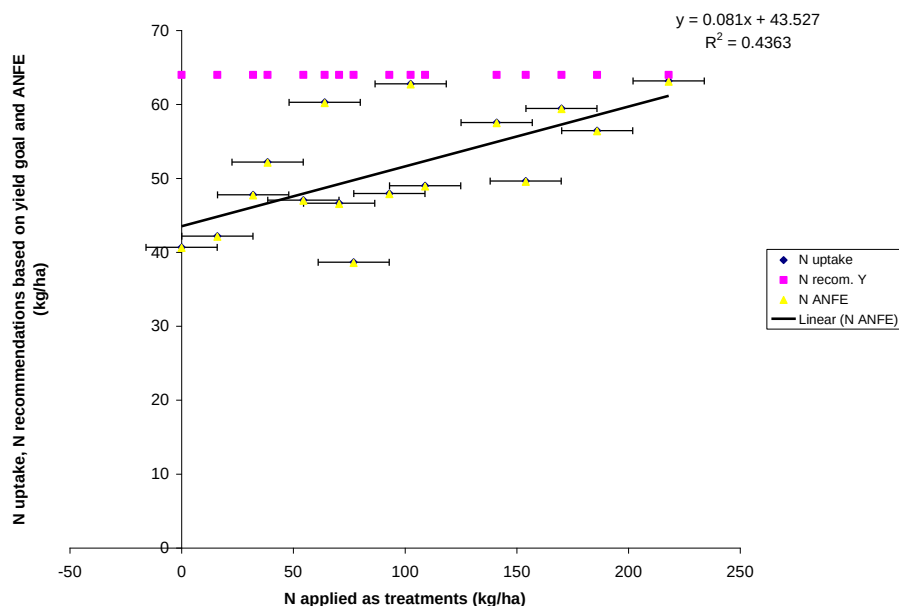


Figure 7: Relationship of N applied as treatment with uptake by sorghum, N recommendation based on yield goal and N recommendation based on ANFE

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