

Evaluation of Nitrogen Mineralization Dynamics Following Amendments Application under Cropping Systems on a Ferric Acrisol in Ghana

V. Logah, E.Y. Safo and C. Quansah

Abstract—Published information on the dynamics of nitrogen mineralization under different amendments and cropping systems on the field is lacking. Earlier studies focused on nitrogen mineralization under laboratory conditions, results of which may be of limited importance under field conditions. To bridge this gap in knowledge, a field experiment was conducted on a Ferric Acrisol in 2006 and 2007 in the semi – deciduous forest zone of Ghana. The experiment was arranged in a split – plot with three replications. Three different amendments (poultry manure, poultry manure + chemical fertilizer, chemical fertilizer and a control (no amendment) constituted the sub-plots whereas selected cropping systems (continuous maize, maize/soybean intercrop and maize/cowpea rotation) were assigned to the main plots. The experiment was conducted in three consecutive cropping seasons and the rate of nitrogen mineralization monitored at 3, 6, 9 and 12 weeks after application of amendments (WAA) within each season. The results indicated changes in the level of NO_3^- and NH_4^+ over time. Nitrate- nitrogen was generally low and rose to higher levels at the occurrence of ‘Birch effect’ when the control registered higher values (19.32 - 80.89 mg NO_3^- kg⁻¹ soil) than amended plots (12.83 - 80.49 mg NO_3^- kg⁻¹ soil). Unlike NH_4^+ - N, NO_3^- - N showed immobilization in amended plots as PM and PM + CF plots recorded -0.11 mg/kg each at 9 WAA in 2007 major season. The ratios of NH_4^+ -N: NO_3^- -N varied considerably in the seasonal cycles with generally least values (0.1 - 1.3) recorded at the occurrence of Birch effect. Cropping systems significantly ($P < 0.05$) influenced NH_4^+ -N: NO_3^- -N ratios in all seasons of study. The study has established that ‘Birch effect’ is characterized by immobilization of nitrate under amendments and lower NH_4^+ : NO_3^- ratios. Crop removal of NO_3^- - N and NH_4^+ - N was generally different for the cropping systems considered.

Index Terms— Amendments, cropping systems, mineralization, nitrogen.

I. INTRODUCTION

Nitrogen is the nutrient that is most frequently limiting to crop production and the nutrient applied in the greatest amounts [8]. Nitrogen deficiency has been widely reported in

Ghanaian soils [10], [19]. Given the widespread prevalence of nutrient stresses worldwide, a thorough understanding of acquisition, mineralization and dynamics of nutrients at the level of the cropping system is essential [3].

In attempt to curtail the declining nitrogen contents of soils, many studies have focused on fates of nitrogen inputs during one or more growing seasons and many chemical and biological assays have been developed to predict nitrogen availability to crops [6]. However, less is known about how the dynamics of the actual process of mineralization that leads to nitrogen availability is affected by amendments and cropping systems over time. Above all, most mineralization studies were carried out in the laboratory and the results used to elucidate field mechanisms. The consequence is underestimation of the process. Laboratory incubations can in some cases predict the maximum nitrogen mineralization potential [7] although underestimation also occurs compared to nitrogen mineralization in the field [15]. A field study was, therefore, conducted in 2006 and 2007 at Kwadaso, Kumasi, Ghana to monitor the dynamics of nitrogen mineralization as affected by different amendments and cropping systems and to investigate crop removal of the nutrient at different stages of plant growth.

II. MATERIALS AND METHODS

Study site description

The study was conducted at the Soil Research Institute, Kwadaso, Kumasi in 2006 – major, 2006 – minor and 2007 – major seasons. Geographically, the area lies between latitudes 060.39’ and 060.43’ North and longitudes 010. 39’ and 010.42’ West of the Greenwich meridian and is located in the semi-deciduous forest zone of Ghana. The area is characterized by a bimodal rainfall distribution. The major rainy season starts from March - July and the minor season starts from September - November. There is a short dry period in August. The mean annual precipitation is about 1500 mm while mean monthly temperatures range from 24 - 28 oC. The soil of the study area is classified as Ferric Acrisol [11] and Typic Haplustult [20].

Initial soil analysis of the site in 2006 showed a pH of 6.7 in 1:2.5 suspension of soil and water. Soil texture was determined by the hydrometer method and was found to be sandy loam. Organic carbon ranged from 1.08 – 1.36%. Other soil chemical properties of the site were total N, 0.07 %, available P, 45.13 mg kg⁻¹ soil, exchangeable K, 0.38 cmol kg⁻¹ soil.

Manuscript received November 15, 2010. The authors wish to express their sincere gratitude to the Ghana Education Trust Fund (GETFUND) for funding this work through the KNUST Scholarship.

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Field experiment

Experimental design and treatments

The experiment was laid in a split plot arranged in randomized complete block design (RCBD) with three replications. The cropping systems (continuous maize - CM, maize/ soybean- M/S intercrop and maize/ cowpea- M/C rotation) constituted the main plot factors. Three different amendments and a control (no amendment) constituted the sub - plots. Poultry manure – PM (4 t ha⁻¹), chemical fertilizer – NPK 15 – 15- 15 (60 – 60 – 60 kg ha⁻¹) and poultry + chemical fertilizer (2 t ha⁻¹ PM + 30 – 30– 30 kg ha⁻¹ NPK) were applied by the method of side placement at two weeks after planting. At 5 weeks , PM + CF and CF plots were ‘top dressed’ with nitrogen at the rate 15 kg ha⁻¹ and 30 kg ha⁻¹, respectively. The cultivars of the test crops were maize (Dorke SR), cowpea (Soronko) and soybean (Ahoto). The total land area measured 42.5 m x 14.0 m (595.0 m²).

Soil sampling

Soil samples were taken at the depth of 0 – 15 cm during each season at the intervals of 3, 6, 9 and 12 WAA. The fresh samples were used for the mineralization analysis.

Laboratory/analytical methods

The determinations of both NO₃⁻-N and NH₄⁺-N were by the method of colorimetry as described by [1].

Nitrate -nitrogen (NO₃⁻-N) determination

The determination of nitrate in the soil sample involved an extraction with 0.5 M K₂SO₄. Ten grams of fresh soil was shaken in 30 ml of extractant (0.5 M K₂SO₄) for 30 minutes. After filtration through Whatman No. 42 filter paper, nitrate in the clear solution was determined by the colorimetric method. A 2 ml aliquot of the extract was pipetted into a test tube. To this was added 1 ml salicylic acid solution which was prepared by dissolving 5 g salicylic acid in 95 ml concentrated sulphuric acid [1]. The resulting solution was allowed to stand for 30 minutes after which 10 ml of 4.0 M sodium hydroxide solution was added and mixed well. Following 1 hour of full colour development, the absorbance of the yellow colour was read at a wavelength of 410 nm on a spectronic 21 D spectrophotometer.

A standard series of 0, 2, 4, 6 and 8 mg/l NO₃⁻-N was prepared in 50 ml volumetric flasks from a 50 mg/l NO₃⁻-N stock solution. The absorbance for each standard was then read on the spectrophotometer. A standard curve was obtained by plotting a graph of absorbance against standard concentrations. The solution concentrations for sample and blank were determined from the curve. The blank value was then subtracted from the sample value to give a value for corrected concentration, C.

Calculation:

$$NO_3^- - N \text{ (mg / kg soil)} = \frac{C \times V}{V} \quad (1)$$

where

C = corrected concentration (mg/l)

V = extract volume (ml)

W = weight of sample (g)

Ammonium - nitrogen (NH₄⁺-N) determination

The NH₄⁺-N was determined from the same extract as NO₃⁻-N above. A 2 ml aliquot of the extract was pipetted

into a test tube to which two different reagents (RI and RII) were added. RI was prepared by mixing three separately prepared solutions namely: 4 % EDTA (5 ml), 0.05 g/ml sodium nitroprussite (100 ml) and 1.12 g/ml sodium salicylate (50 ml). RII was prepared by dissolving 0.2 g of sodium dichlorocyanate in 10 ml of distilled water and transferred to a 200 ml flask. The volume was made up to the mark with a buffer solution of 0.0746 M Na₂HPO₄.12H₂O (adjusted to pH 12.3). The resulting solution was allowed to stand for 2 hours after the addition of 3 ml and 5 ml of RI and RII, respectively.

Working standards of 0, 5, 10, 15 and 20 mg/l were prepared from 1000 mg/l NH₄⁺-N stock solution. The absorbance of the sample, blank and working standards were read on the spectrophotometer at a wavelength of 660 nm. A graph of absorbance against standard concentrations was plotted. Solution concentrations for the sample and blank were then determined. The blank value was subtracted from the sample value to give a value for corrected concentration, C.

Calculation

$$NH_4^+ - N \text{ (mg / kg soil)} = \frac{C \times V}{V} \quad (2)$$

where

C = corrected concentration (mg/l)

V = final digest or extract volume (ml)

W = weight of sample (g)

Statistical analysis

The collected data was subjected to analysis of variance (ANOVA) using the GenStat statistical package [12]. Separation of means was done using the least significant difference (LSD) method at P = 0.05.

III. RESULTS

The seasons recorded changes in the level of NO₃⁻-N over time. The 2006 - major season registered an increase in the level of NO₃⁻-N from 3 to 6 weeks and peaked at 9 weeks after amendments application (WAA) (Table 1). This was followed by a sharp decline at 12 WAA. Recorded values of NO₃⁻-N in the 2006 - minor season generally followed increasing pattern (Table 2). The 2007 - major season however, registered a decrease in the level of NO₃⁻-N between 3 to 6 weeks following amendment except for CTRL and PM + CF plots (Table 3). At 63 days following amendment (9 WAA), there was a sharp decline which was characterized by immobilization in amended plots including the control except in plots amended with only chemical fertilizer (CF) (Table 3).

At 3 WAA, chemical fertilizer amended soils differed significantly (P < 0.05) in NH₄⁺ from all soils in the 2007 - major season. At 6 WAA, there were no significant differences (P > 0.05) between amendments in all seasons (Table 3). At 9 and 12 WAA, chemical fertilizer treated plots produced significantly higher NH₄⁺-N than PM and PM + CF amended plots. Ammonification under the cropping systems did not follow any specific trend. Unlike NO₃⁻-N, ammonium - N showed no immobilization in amended plots at 9 WAA (Table 3).

TABLE 1. DYNAMICS OF NO₃⁻-N AND NH₄⁺-N UNDER TREATMENTS IN 2006 - MAJOR SEASON ON A FERRIC ACRISOL

Treatment	3 WAA	6 WAA				9 WAA	12 WAA	
	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺
Amendment								
CTRL	3.90	5.13	4.10	7.4	30.2	5.2	1.26	6.09
PM	5.99	6.07	6.86	11.00	27.4	6.18	1.63	7.85
PM + CF	6.09	6.98	6.23	10.80	21.9	12.66	2.33	7.08
CF	6.19	7.83	7.43	9.1	24.2	30.98	3.81	17.09
LSD (P < 0.05)	0.90	0.24	1.31	1.32	7.31	1.46	0.88	1.32
Cropping system								
CM	6.10	9.31	6.94	13.6	21.7	14.31	2.42	9.17
M/S	3.82	4.20	4.93	4.40	32.7	13.68	2.26	9.98
M/C	4.98	8.72	6.58	10.6	23.5	13.27	2.11	9.4
LSD (P < 0.05)	1.05	1.7	1.74	1.62	11.13	2.38	0.73	1.74

WAA - Weeks after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer.

TABLE 2. DYNAMICS OF NO₃⁻-N AND NH₄⁺-N UNDER TREATMENTS IN 2006 - MINOR SEASON ON A FERRIC ACRISOL

Treatment	3 WAA	6 WAA			9 WAA		12 WAA	
	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺
Amendment								
CTRL	3.07	3.55	3.90	5.18	5.38	5.84	27.20	7.47
PM	4.36	3.67	5.40	4.78	5.97	6.54	22.60	9.86
PM + CF	3.60	3.02	5.20	5.11	5.94	7.00	18.40	11.33
CF	4.66	4.67	5.80	5.35	6.27	8.31	23.80	15.85
LSD (P < 0.05)	0.97	1.46	0.79	1.12	2.36	2.04	5.43	3.99
Cropping system								
CM	3.79	3.75	3.00	4.87	5.34	7.79	21.00	10.85
M/S	3.51	3.91	6.50	4.66	4.97	6.21	20.80	11.08
M/C	4.46	3.53	3.40	5.78	1.27	6.57	27.30	11.45
LSD (P < 0.05)	1.09	0.99	1.14	0.97	0.73	2.17	6.51	3.04

WAA - Weeks after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer

TABLE 3. DYNAMICS OF NO₃⁻-N AND NH₄⁺-N UNDER TREATMENTS IN 2007 - MAJOR SEASON ON A FERRIC ACRISOL

Treatment	3 WAA	6 WAA			9 WAA		12 WAA	
	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺	NO ₃ ⁻	NH ₄ ⁺
Amendment								
CTRL	80.89	3.93	82.42	4.49	-4.25	3.60	19.32	2.77
PM	65.93	4.21	64.12	4.65	-0.11	5.74	14.83	2.87
PM + CF	69.98	4.63	77.62	4.71	-0.11	5.33	14.03	2.95
CF	80.49	11.95	63.75	4.90	2.40	6.13	12.83	4.31
LSD (P < 0.05)	10.71	1.04	9.67	0.92	0.19	0.70	4.33	1.09
Cropping system								
CM	77.14	5.54	75.27	4.56	0.74	5.15	15.35	2.75
M/S	77.13	6.62	72.03	4.61	-2.04	4.54	14.05	3.29
M/C	68.52	6.38	68.65	4.89	-0.32	5.17	13.35	2.88
LSD (P < 0.05)	11.31	1.79	12.14	1.67	0.33	1.86	4.51	0.94

WAA - Weeks after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer.

TABLE 4. DYNAMICS OF NH₄⁺-N : NO₃⁻-N RATIOS UNDER TREATMENTS IN 2006 - MAJOR SEASON A FERRIC ACRISOL

Treatment	NH ₄ ⁺ -N : NO ₃ ⁻ -N			
	3WAA	6 WAA	*9 WAA	12 WAA
Amendment				
CTRL	1.3	1.8	0.2	4.8
PM	1.0	1.6	0.2	4.8
PM + CF	1.1	1.7	0.6	3.0
CF	1.3	1.2	1.3	4.5
LSD (P < 0.05)	0.19	0.24	0.07	1.51
Cropping system				
CM	1.5	2.0	1.7	3.8
M/S	1.1	0.9	0.4	4.4
M/C	1.8	1.6	0.6	4.5
LSD (P < 0.05)	0.21	0.38	0.27	1.89

WAA - Weeks after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer,* 9 WAA: marked by occurrence of Birch effect.

TABLE 5. DYNAMICS OF NH_4^+ -N : NO_3^- -N RATIOS UNDER TREATMENTS IN 2006 - MINOR SEASON ON A FERRIC ACRISOL

Treatment	NH_4^+ -N : NO_3^- -N			
	3WAA	6 WAA	9 WAA	*12 WAA
Amendment				
CTRL	1.2	1.3	1.1	0.3
PM	0.8	0.9	1.1	0.4
PM + CF	0.8	1.0	1.2	0.6
CF	1.0	0.9	1.3	0.7
LSD (P < 0.05)	0.14	0.26	0.22	0.13
Cropping system				
CM	1.0	1.6	1.5	0.5
M/S	1.1	0.7	1.2	0.5
M/C	0.8	1.7	5.2	0.4
LSD (P < 0.05)	0.19	0.30	0.20	0.09

WAA - Weeks after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer, * 12 WAA: marked by occurrence of Birch effect.

TABLE 6. DYNAMICS OF NH_4^+ -N : NO_3^- -N RATIOS UNDER TREATMENTS IN 2007 - MAJOR SEASON ON A FERRIC ACRISOL

Treatment	NH_4^+ -N : NO_3^- -N			
	*3WAA	* 6 WAA	9 WAA	*12 WAA
Amendment				
CTRL	0.1	0.1	- 0.8	0.1
PM	0.1	0.1	- 52.2	0.2
PM + CF	0.1	0.1	-48.5	0.2
CF	0.2	0.9	2.6	0.3
LSD (P < 0.05)	0.01	0.1	0.01	0.04
Cropping system				
CM	0.1	0.1	7.0	0.2
M/S	0.1	0.1	-2.2	0.2
M/C	0.1	1.1	-16.2	0.2
LSD (P < 0.05)	0.02	0.01	0.02	0.04

WAA - Weeks after amendment, CTRL: Control, PM: Poultry manure, PM + CF: Poultry manure + chemical fertilizer, CF: chemical fertilizer, * 3, *6, *12 WAA: marked by occurrence of Birch effect.

The ratios of NH_4^+ -N : NO_3^- -N varied considerably in the seasonal cycles (Tables 4 - 6). At 3 WAA in 2006 - major season, plots that received PM amendment recorded the least value of 1.0 which differed significantly ($P < 0.05$) from those of PM + CF and CF plots (Table 5). At 6 WAA in 2006 - minor season, plots under no amendment (CTRL) recorded the highest value whilst CF amended plots gave the highest following 12 WAA (Table 5). The 2007- major season however, recorded the lowest (-52.2) at 9 WAA for PM treated soils and highest (0.3) for CF treated plots on the 12 WAA (Table 6). Cropping systems significantly ($P < 0.05$) influenced NH_4^+ -N : NO_3^- -N ratios in all seasons of study.

IV. DISCUSSION

Nitrate - N at the level of the amendments and cropping systems followed an increasing pattern in the minor season. A similar observation was made by [17] when they found in cereals and legumes cropping systems that NO_3^- levels increased gradually over time. The relatively higher nitrate - nitrogen recorded at 9 and 12 weeks following amendment in 2006 - major and 2006 - minor seasons, respectively and also at 3, 6 and 12 WAA in 2007 - major season was possibly due to 'Birch effect'. There is often a marked seasonality of organic matter decomposition in the wet and dry tropics due to a flush of decomposition associated with the rewetting of dry soils [5, 2]. Results of this study showed that the 'Birch effect' was characterized by immobilization of nitrate in the amended plots as the control nitrate values were consistently higher than those of the amended plots. The flush of nitrate

associated with occurrence of 'Birch effect' by virtue of the decomposition of organic matter was carried out by nitrifying bacteria (e.g. *Nitrosomonas*). According to [14], these microorganisms obtain most of their energy from the process itself. The microbes in obtaining their energy from the process, immobilized the nitrate in the amended plots.

The recorded NH_4^+ -N during the cropping seasons showed changes in its level in the soil over time. This could be due to the microbiological activity and the influence of crop uptake at different stages of growth and was in contrast with the observation of [17] who reported constant pool size of NH_4^+ -N. Like nitrate -N, values recorded for ammonium-N in the 2006 - minor season followed increasing pattern over time (Table 2). Comparatively, levels of NO_3^- -N and NH_4^+ -N did not show consistency. The NO_3^- -N levels were higher than NH_4^+ -N at the 3 and 6 WAA under amendments in the 2007- major season whilst NH_4^+ -N was higher at the 9th week of the same season. At the 12 WAA in 2006-minor season, NO_3^- -N was higher than NH_4^+ -N (Table 2). According to [9], the lowest NO_3^- -N and NH_4^+ -N concentrations were obtained during the rainy season and the highest during the winter, with extractable NH_4^+ -N always higher than extractable NO_3^- -N. Data from this study indicated no immobilization of NH_4^+ by soil microbes as was recorded for NO_3^- . This contrasted a report by [4] that the NH_4^+ -N has been found to be the preferred form of N for assimilation by microbes in many cultivated soils. In some agricultural soils, no NO_3^- immobilization has been observed [18]; while in others NO_3^- immobilization was recorded after

1 - 4 weeks [16] or several months [13].

The effects of amendments and cropping systems on NH_4^+ - N: NO_3^- - N ratios have received little attention in most studies. The few instances reported in literature focused only on the effect of crop uptake on these ratios. For example, [21] investigated the relative rates of NH_4^+ and NO_3^- uptake by corn using solution -culture experiments in a controlled - climate chamber. The researchers used five NH_4^+ - N : NO_3^- - N ratios ranging from 8.40 to 0.17 and found no significant differences in relative rates of absorption of NO_3^- and NH_4^+ . This study however, investigated the impact of amendments under different cropping systems on NH_4^+ -N: NO_3^- -N ratios. Generally, the lowest ratios were produced at 9 WAA in 2006 - major season, 12 WAA in 2006 - minor season and at 3, 6 and 12 WAA in 2007-major season. These low ratios were due to the high levels of NO_3^- -N recorded by virtue of 'Birch effect'. This observation was consistent with the occurrence of 'Birch effect'. The negative values recorded in CTRL, PM, PM + CF, CM, and M/C plots at 9 WAA in 2007- major season (Table 6) were due to nitrate -N immobilization at 9 WAA (Table 3) in these plots.

V. CONCLUSION

This study has established that 'Birch effect' is characterized by immobilization of nitrate under amendments and could also be marked by lower NH_4^+ - N/ NO_3^- - N ratios. Results have shown that NO_3^- - N unlike NH_4^+ - N, could be subject to immobilization under amendments during a cropping cycle. The recorded NH_4^+ - N during the cropping seasons showed changes in its level in the soil over time (especially at the level of the amendments) indicating differences in crop removal at the different stages of growth.

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