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Nitrogen Mineralization Potential (N_o) in Three Kenyan Soils, Nitisols, Ferralsols and Luvisols

George N. Karuku[1] & Benson O. Mochoge[2]

[1] Faculty of Agriculture, University of Nairobi, Nairobi, Kenya

[2] School of Agriculture and Enterprise Development, Kenyatta University, Nairobi, Kenya

Correspondence: George N. Karuku, Faculty of Agriculture, University of Nairobi, P.O. Box 30197-00100 GPO, Nairobi, Kenya. E-mail: karuku_g@yahoo.com

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Abstract

Nitrogen mineralization potential is important so as to prevent over-fertilization that could lead to groundwater contamination or under-fertilization that could lead to poor nutrient provision by crops leading to low yields. Three soil types were selected on the basis of groups, agro-ecological zone, organic matter content and land use. The soil samples were taken from the 0-15 and 15-30 cm depth. The samples were placed in incubation bags, water added to field capacity, sealed and incubated in laboratory at room temperature. The bags were opened at intervals of two weeks and soil sub-samples taken for analysis of mineral N for a period of 17 weeks. The calculated mineralizable N was 138.8 µg N and 116.4 µg N/g for Gituamba andosols, 46.0 µg N and 46.4 µg N/g for Kitale ferralsol and 260.1 µg N and 197.3 µg N/g soil for Katumani luvisols in the 0-15 and 15-30 cm depth, respectively. These calculated values compared well with the actual cumulative mineralizable N for Gituamba andosols at 127 µg N and 74.1 µg N/g, for Kitale ferralsols at 48.0 µg N and 64.1 µg N/g and for Katumani 80.6 µg N and 47.7 µg N/g soil in the 0-15 and 15-30 cm depth, respectively. The time taken for 50% of potentially mineralizable N to be mineralized ($t½$) ranged from 6.3 weeks for Katumani luvisols 15-30 cm to 30.1 weeks for Kitale ferralsols 0-15 cm soil depths. The soils with highest rate constant (k) had the least. For example, 15-30 cm depth of Katumani luvisols with of 6.3 weeks had the highest k of 0.112 $week^{-1}$ compared with Kitale ferralsols 0-15 cm depth with $t½$ of 30.1 weeks and the lowest k of 0.023 $week^{-1}$. The observed data indicates that 50% of N would be mineralized in all the soil types with the exception of Kitale ferralsols (0-15 cm depth) within the growing period of the crops which is approximately 20 weeks.

Keywords: nitrogen mineralization potential (N_o), mineralization rate constant (k), $t½$

1. Introduction

Nitrogen (N) is the one of the most limiting factor to the growth of almost all crops in terrestrial ecosystems. The dynamics of inorganic nitrogen (NH_4^+, NO_3^-) has been intensively studied in soils, and increasingly research has been focused on the dynamics of soil organic nitrogen in agricultural soils. Nitrogen in soil surface is predominantly in organic (≈ 98%) forms (Bremner, 1951). In this form, N is unavailable for plant and microbial use in the soil. It means therefore that it has to be converted to forms available for plant use, that is, NH_4^+, NO_3^-. The rhizosphere is the soil zone in which microbial activity is influenced by plant roots most, distinguishing it from 'bulk' soil (Berendsen et al., 2012; Garbeva et al., 2004; Herman et al., 2006; Marschner et al., 2001). Active interaction occurs among plant roots, soil, and microbes in rhizosphere soils (Herman et al., 2006; Lamberset al., 2009; Singh et al., 2004). The interaction results in increase in soil nitrogen mineralization, which correspondingly increases net plant nitrogen assimilation (Bardgett & Chan, 2009; Bregliani et al., 2010).

The conversion of organic N to more mobile, inorganic state is known as "Nitrogen mineralization" and is accomplished in two steps; ammonification (production of NH_3 from organic matter) and nitrification (conversion of NH_4^+ to nitrates) (Myrold & Bottomley, 2008). The reverse *i.e.* incorporation of inorganic to organic forms, is known as immobilization. The opposing processes, immobilization-mineralization occurs simultaneously in most ecosystems, for example in soil, where organic material is undergoing microbial decomposition. Mineralization of N is the result of metabolism of a multitude of microbial strains, mostly chemo-heterotrophs (Buckman & Brady, 1969; Reddy et al., 2009). Because the ultimate liberation of NH_4^+ from organic matter (OM) is associated with many physiologically dissimilar microorganisms (MOs), N is mineralized in most extreme

conditions (Alexander, 1977). However, the amount of NH_4 that accumulates varies with the nature of organisms, the substrate, the soil type and environmental conditions.

The breakdown of organic compounds containing N is through proteolytic enzymes synthesized extracellular by MOs. The process is known as proteolysis, whereby proteins are hydrolyzed into simpler units of peptides and amino acids. The release of NH_4^+ is then accomplished from amino acids through ammonification process. The rate of mineralization-immobilization is influenced by the C: N ratio, type of organic substrate, soil moisture content, temperature and aeration of soil (Zaman & Chang, 2004). Significance of some soil variables to N mineralization has been established under laboratory conditions. These variables include texture with emphasis on varying aggregate sizes (Craswell & Waring, 1972; Van Veen & Kuikman, 1990), soil moisture where mineralization has been found to vary directly within available range (Reichman et al., 1966; Karuku, 1989; Van Veen & Kuikman, 1990) and OM, particularly that which accumulates under pasture (Huntjens, 1972). Other factors being equal, production of inorganic N has been shown to be greater in neutral than in acid soils (Ishaque & Cornifield, 1972; Mochoge, 1981), although some soils show little influence of pH on N transformations.

Stanford et al. (1974) developed a concept of potentially mineralizable soil nitrogen, the fractional quantity that is susceptible to first order kinetics; expressed in equation form as: $dn/dt = kn$; by integration, it gives:

$$\log(N_o - N_t) = \log N_o - k_t/2.303 \quad (1)$$

Where, N_o: nitrogen mineralization potential; k: mineralization rate constant. Stanford et al. (1974) found k, was reasonably equal for a large number of soils and that a period of two weeks incubation following short term pre-incubation (1 or 2 weeks) is sufficient to estimate the mineralization potential (N_o) and then proposed a simplified equation to estimate N_o:

$$N_o = 9.77\ N_t \quad (2)$$

Where, N_t is nitrogen mineralized in two weeks.

Dealing with five soil types, Stanford et al. (1974) reported that rate of N mineralization was proportional to the quantity of N comprising mineralizable substrate. Cumulative inhibitory effects during incubation have been reported by some workers such as drop in pH during a 23 week continuous incubation period (Allison & Sterling, 1949). The H^+ ions released through nitrification during incubation were thought to lower the soil pH. Enzymatic conversion of organic N substances yielding NH_4^+ ions is also considered a rate limiting step in N mineralization and the reaction is not viewed as diffusion controlled. The low N mineralization during initial stages of incubation is considered to reflect the lag phase (Mochoge & Beese, 1985; Sing & Beauchamp, 1986; Stanford & Smith, 1972). It could also be due to assimilation of N by organisms, owing to decomposition of small amounts of low N plant materials (Stanford & Smith, 1974).

Correlation of N mineralization in two weeks and N_o are usually low but improve with time just as is the case for cumulative net N mineralization. The estimates of potentially mineralizable soil N derived from short-term are similar to those derived after extensive incubation and that N_o has intrinsic values in predicting amount of N mineralized under specified conditions (Stanford & Smith, 1974).

2. Materials and Methods

2.1 Research Methodology

The need for satisfactory laboratory methods for obtaining an estimate of the amount of N likely to be made available for crop growth by mineralization of soil organic matter (SOM) during the growing season of a crop has been a matter of great concern. Numerous studies of biological and chemical approach have been conducted (Keeney & Bremner, 1966; Gianello & Bremner, 1986; Stanford & Smith, 1972; Stanford, 1982). It is generally accepted that the most reliable methods currently available are those involving determination of inorganic N produced by incubation of soil samples under aerobic and anaerobic conditions (Runge, 1974; Mochoge, 1981; Stanford, 1982; Gianello & Bremner, 1986). Incubation of soil samples in situ involves burying of soil samples in polythene or mesh bags under soils at different depths from sites of sampling and monitoring frequently the inorganic N release (Runge, 1974). The method exhibits some field conditions but use of disturbed soil samples and sand-witching of bags in between soil layers puts it slightly off from actual field situations in terms of moisture and air regimes. Moreover bags used have been often attacked by insects and therefore the results have not been very reliable.

Different incubation methods have been used and these include incubating soils in situ (in bags), use of column studies and incubating of soil samples in polythene bags in the laboratories.

Three soil types were selected on the basis of groups, agro-ecological zone, organic matter content and land use. These were the Gituamba andosols, Kitale ferallsols and Katumani luvisols (WRB, 2006). Gituamba is centered on coordinate 0°45′S-36°51′E where the Geology is mainly Basalts and Basaltic Conglomerates of Simberian Series. The land is under tea and pyrethrum cultivation under ecological zone II; P/E 82%. The soils are acidic, well drained dark to dark-reddish clay. The Kitale ferralsols were sampled on center coordinates 1°01′N-34°39′E and the Geology consists of Basement system of Gneisses, Schists rich in Feldspars, Biotite, Horneblende and Garnet with minor exposure of granite and Pegmatitic dykes. The land is mainly used for maize cultivation and pasture research. It is in agro-Eco-zone III, P/E 66%. The soils on one side are well drained deep to moderately deep, reddish brown to yellowish red, friable clay on upper valley slopes. The other is poorly drained dark grayish brown in valley bottoms. Main clay mineralogy is kaolin. There are significant quantities of illite and montimorrillonite. The Katumani luvisols are on coordinates 1°35′S-37°14′E. The Geology of the area is mainly Quartzo-feldspartic gneiss of the Precambrian basement system. The land was originally under Acacia bush which has been cleared to pave way for Cereals such as maize, Sorghum and also beans and pastures. It is in Eco-zone IV. The soils are well drained sandy clay.

2.2 Soil Sampling

The soil samples were taken from the 0-15 and 15-30 cm depth. A profile pit 40 cm deep was dug and the 15-30 cm depth sampled first to avoid contamination from above layer. The samples were placed in special sampling bags, sealed and placed in cool boxes before transportation to the laboratory for processing. Undisturbed samples were also taken using core rings for physical determinations of bulk density and hydraulic conductivity.

2.3 Soil Analysis

Total Nitrogen and available N were determined in accordance with micro-Kjeldhal method described by Bremner (1996). For Non-exchangeable ammonium N that is fixed, 1 gram of air dried soil (< 2 mm) was weighed into a 400 ml beaker. To it was added 20 mls of potassium hypobromite solution and shaken. The beaker was then covered with a watch glass and allowed to stand for 2 hours (to get rid of exchangeable NH_4^+ ions and labile organic compounds). After 2 hours, 60 mls of distilled water was added and the mixture strongly boiled for 5-6 minutes. The mixture was allowed to stand overnight and the supernatant decanted. The residue was transferred to a 250 ml polythene centrifuge tubes with 0.5 N KCl from plastic watch bottles. The centrifuge tubes were filled to the 80 ml mark and centrifuged for 20 minutes by 1000 × G rev/min and again the supernatant discarded. The remaining residue was then transferred to a 250 ml digestion flask with distilled water and 7 mls Conc. H_2SO_4 and 0.5 g K_2SO_4 added, and digestion commenced. The digestion started at low temperatures until the mixture cleared (30 minutes) and the temperature then raised to the end of digestion (90 minutes). The mixture was allowed to cool, but before cooling completely, small amounts of distilled water was added to prevent solidification of digest. The digest was transferred into a distillation flask and 40 mls of 10 N NaOH added quickly to avoid escape of ammonia gas before actual distillation commenced. The NH_3 gas released during distillation was collected in 20 mls of 1% boric acid with a mixed indicator. Titration was done with 0.01 N H_2SO_4 and the indicator turned from green to pink. Calculation done as per Equations 3 and 4:

$$0.01\ \text{N}\ H_2SO_4 = 140\ \mu\text{g N; hence } \%\text{N} = \frac{(Titre - Blank) \times 140}{10^5} \quad (3)$$

$$\text{Kg N/ha} = \frac{Soil\ depth \times Bulk\ density\ conc.\ (\mu\text{g N}) \times Area\ (\text{cm}^2)}{Weight\ of\ soil \times 10^9} \quad (4)$$

2.4 Statistical Analysis

The data was subjected to Regression analyses using GenStat edition 18 and in this case at how strongly N_o and organic carbon (C) are linearly related by obtaining the correlation coefficients at $\alpha = 0.05$ (https://www.youtube.com/watch?v=BVy3PEht3jA). In this case the data regressed was the N_o against organic carbon since carbon has a higher bearing on climate, agro-ecological zone, soil types and the amount of N to be released.

3. Results and Discussion

3.1 Soil Characterization

The behavior of nitrogen in soils is controlled by the physical, chemical and biological properties of the soil. This being the case, it was therefore necessary to know some of the salient soil properties of the three soils used. Table 1 shows the physical and chemical characteristics of the three soils namely; Gituamba andosols, Kitale ferralsols and Katumani luvisols. The soil pH varied within the soil depths and across the soil groups. The pH ranged from 4.0 in Gituamba andosols (0-15 cm) to 7.0 in Katumani luvisols (15-30 cm) depths. The pH is markedly influenced by the parent material and climatic conditions of the site.

Gituamba area is relatively humid and soils derived from volcanic activity hence low pH. Low pH also has a marked influence on Exchangeable Aluminium (Al) as clearly seen in Gituamba andosols with highest Al content of 4.6 me in the 0-15 cm and 3.3 me/100 g soil in the 15-30 cm depth, respectively. Analyzed Al was found to be highly negatively correlated to soil pH ($r = -0.88$, $P = 0.05$), meaning that as pH decreased, the Al content increased and vice versa as in the case of Gituamba soils. The pH was also found to be significantly and positively correlated with percent base saturation ($r = 0.86$, $P = 0.05$).

The soils also gave different though expected pattern of organic carbon (OC) and total nitrogen (TN) distribution in soil profiles. Both the %OC and TN decreased with depth within soil profile, a phenomenon undoubtedly due to the addition of organic matter mainly at the top. Nitrogen is an integral part of organic carbon. Gituamba Andosols had the highest of both 7.9 and 0.6 % of OC and TN, respectively.

Table 1. Some salient soils characteristics of the study

Soil sampling site and groups	Gituamba andosols		Kitale ferralsols		Katumani luvisols	
Soil Properties/Depth (cm)	0-15	15-30	0-15	15-30	0-15	15-30
pH-water	4.0	4.1	5.6	5.6	6.6	7.0
pH-KCl	3.9	4.0	4.4	4.5	4.8	5.6
CEC (me/100 g soil)	28.6	26.7	15.3	13.4	13.4	12.1
ECEC(me/100 g soil)	11.6	10.2	11.4	9.1	9.5	10.7
Ca(me/100 g soil)	0.7	0.3	4.7	2.9	5.7	6.3
Mg(me/100 g soil)	0.5	0.1	2.4	2.0	1.3	1.9
Na(me/100 g soil)	0.5	0.4	1.0	0.5	0.6	0.4
K(me/100 g soil)	4.3*	3.3*	1.5	1.2	1.5	0.9
% Base Saturation	21.0	19.5	62.7	55.2	61.4	78.5
Exch Al^{3+} (me/100 g soil)	4.6	3.3	1.0	0.8	1.1	0.9
Exch H^{+}(me/100 g soil)	1.0	0.7	0.9	0.9	0.4	0.3
Available P (ppm)	12.5	10.0	2.5	1.5	46.0	29.0
% Total N	0.6	0.5	0.2	0.1	0.2	0.1
% Organic C	7.9	4.8	4.5	1.8	1.0	0.5
C:N	12.8	9.2	22.5	13.9	5.7	5.3
Bulk Density (g/cm^{-3})	0.6	0.8	1.2	1.1	1.4	1.3
% Sand	40.3	38.3	41.9	37.3	68.6	74.2
%Clay	19.9	27.9	52.9	55.0	23.9	22.4
%Silt	39.8	33.8	5.2	7.7	7.5	3.4
Textural Class	Loam	Loam	Clay	Clay	Sandy Clay Loam	Sandy Clay Loam

Note. C: N = Carbon to Nitrogen Ratio; CEC = Cation exchange capacity; ECE = Effective cation exchange capacity.

The C: N ratio differed in the two depths in all soil groups with the ratio lower in the 15-30 cm depth. Low C: N ratio ranged from 5.3 in Katumani luvisols, to 22.5 in Kitale ferralsols 0-15 cm depths. C: N rations are controlled by conditions such as moisture, temperatures and presence of substrate to be mineralized. The C: N ratios observed were within the range which favors net N-mineralization (Kaleeem et al., 2015; Karuku & Mochoge, 2016).

Exchangeable potassium (Exch. K) was very low in Kitale ferralsols followed by Katumani luvisols. In Gituamba andosols, Exch. K was high at 3 me/100 g soil. These Andosols are derived from volcanic ash hence high K content. Keter (1974) suggested that East African rocks are often rich in this element especially when derived from volcanic rocks. Generally, Calcium (Ca), Magnesium (Mg), Sodium (Na) and K were higher in top than sub-soil with exception in Katumani luvisols which could partly be due to leaching from above or simply reflect supply of cations from parent rock.

Cation exchange capacity (CEC) is a measure of soil fertility and was observed to be higher in the top than in the sub soils in the soil groups with exception of Katumani luvisols. The Clay content was highest in Kitale ferralsols at 52.9 and 55.0% and lowest in Katumani luvisols at 23.9 and 22.4% in the 0-15 and 15-30 cm depths, respectively for each soil group. Katumani soils had highest sand content at 68.6 and 74.3% for the 0-15 and

15-30 cm depths, respectively. The texture of the three soil groups varied greatly and could have been influenced by such factors as the vegetation of the location, climate as well as the parent material in which the soils were derived. Gituamba soils are loamy; Kitale clayey and Katumani are sandy clay loam.

The bulk density (ρb) was highest in Katumani luvisols at 1.4 and 1.3 g/cm^3 and lowest in Gituamba Andosols at 0.6 and 0.8 g/cm^3 for the 0-15 and 15-30 cm depths, respectively and seems to reflect the texture of respective soils. Soils low in clay content and are high in sand content like Katumani luvisols tend to exhibit higher ρb and vice versa (Chaudhari et al., 2013; Sakin, 2012; Catherine & Ouimet, 2007; Sakin et al., 2011). However, influence of organic matter content on ρb in these soils cannot be ruled out.

3.2 Nitrogen Forms in the Three Soil Groups

Table 2 shows various forms of nitrogen of the three soils groups in kgN/ha. The TN ranged from 1,038.5 kg in Kitale ferralsols (15-30 cm) to 6,558.6 kg/ha in Gituamba andosols (0-15 cm) depths. The TN decrease with depth in all the three soil groups: Gituamba from 6,558.6 to 5,832.7 kg; Kitale from 1,627.0 to 1,038.5 kg and Katumani from 3,582.2 to 1,663.2 kg/ha in 0-15 cm to 15-30 cm depths. Gituamba andosols had the highest amount of TN in the 0-30 cm layer of 12,391.3 kg/ha and Kitale had the lowest at 2,665.5 kg/ha. Again the total amounts reflect climate and vegetation of the area (Onwonga et al., 2010; Karuku & Mochoge, 2016; Naomi, 2017). The same trends were observed in exchangeable ammonium Nitrogen (NH_4^+) and nitrate Nitrogen (NO_3^-) and were higher in the 0-15 cm than in 15-30 cm depth in all three soil groups. Gituamba had highest available N at 319.6 kg/ha in the 0-30 cm layer followed by Kitale at 129.3 kg/ha then Katumani at 28.6 kg/ha.

The %TN in all three soil groups ranged from 0.6 in Gituamba andosols (0-15 cm) to 0.1% in Katumani luvisols (15-30 cm) depths, a range that has been reported in most cultivated soils (Ehud & Israel, 2016; Naomi, 2017; Onwonga et al., 2010). Observed exchangeable NH_4^+-N was very low and ranged from 0.2% in Katumani (0-15 cm) to 3.2% in Kitale (15-30 cm) of the TN in each depth. NO_3^--N on the other hand ranged from 0.2% in Katumani (0-15 cm) to 1.6% in Kitale (0-15 cm) of the TN in each depth. NO_3^--N were lower than exchangeable NH_4^+-N in all three soil groups.

Organic nitrogen showed same trend as TN where Gituamba andosols had the highest amount at 9337.2 kgN/ha followed by Katumani luvisols with 4939.0 kg/ha and Kitale ferralsols the lowest at 2455.0 kg/ha in the 0-30cm depths. Organic N formed the highest portion of the various forms of nitrogen. Organic N formed the highest portion of various N forms and ranging from 75.3 to 95.3% of total N. Gituamba andosols had 75.4 and 75.3%, Kitale ferralsols 92.3 and 91.8% and Katumani luvisols with 95.3 and 91.7% in the 0-15 and 15-30 cm depths, respectively.

Table 2. Nitrogen distribution in the three soil groups: Andosols, Ferralsols and Luvisols (kgN/ha)

Soil group	Depth (cm)	Total-N	Organic-N	Hydrolysable organic-N	Hydrolysable-N as % of organic-N	Available-N	Fixed-N (NH4-f)
Gituamba	0-15	6558.6	4945.2	3742.2	75.7	167.1	1305.2
	15-30	5832.7	4392.0	3499.2	81.5	152.5	1403.9
Andosol	Total	12391.3	9337.2	7241.4	77.6	319.6	2709.1
	% of TN	-	75.4	58.4	-	2.7	21.9
Kitale	0-15	1627.0	1501.7	826.5	55.0	72.5	54.0
	15-30	1038.5	953.3	618.0	64.8	56.8	40.3
Ferralsol	Total	2665.5	2455.0	1444.5	58.8	129.2	94.3
	% of Total	-	92.0	54.2	-	4.7	3.3
Katumani	0-15	3582.2	3413.8	1476.3	43.2	15.1	152.5
	15-30	1663.2	1525.2	768.0	50.4	13.5	116.9
Luvisol	Total	5245.4	4939.0	2244.3	45.4	28.6	269.4
	% of Total	-	94.2	42.8	-	0.6	5.2

Note. TN = Total Nitrogen, N = Nitrogen.

The N distribution in the three soils was highest in organic form ranging from 75.5 to 93.3% of TN in Gituamba andosols and Katumani luvisols, 0-15 cm depth, respectively. This confirms the well stated fact that most N in soils comes from organic matter decomposition unless added from synthetic fertilizers. The other components of N-mineral were low of which the fixed N (NH_4-N_f) comprised the highest amount in this category with amount ranging from 22.1 to 3.8% in Gituamba andosols and Kitale ferralsols, respectively. Available mineral N

(NH_4-N_e and NO_3-N) comprised less than 3.2 and 1.6% in Kitale ferralsols. The ferralsols that had been under grass cover seemed to have more available mineral N compared to the other two soil types.

Table 3. Nitrogen distribution in the three soil types as percentage of total nitrogen

Soil type	Depth (cm)	NH_4-N_e	NO_3-N	NH_4-N_f	Organic-N
Gituamba	0-15	1.9	0.6	22.1	75.4
andosols	15-30	2.1	0.5	22.1	75.3
Kitale	0-15	2.8	1.6	3.3	92.3
ferralsols	15-30	3.2	1.2	3.8	91.8
Katumani	0-15	0.20	0.2	4.3	93.3
luvisols	15-30	0.5	0.3	7.5	91.7

Note. NH_4-N_e = Exchangeable ammonium nitrogen; NO_3-N = Nitrates; NH_4-N_f = fixed nitrogen.

3.3 Nitrogen Mineralization Potential (N_o,) Mineralization Rate Constant (k) and t½ in the Three Kenya Soils

Table 4 shows values of nitrogen mineralization potential (N_o), mineralization rate constant (k), regression coefficient and time taken for 50% of potentially mineralizable N (*t½*) to be mineralized. The *t½* is given by the equation 0.693/k while k is given by equation 2.303 multiplied by the slope of log (N_o-N_t). The calculated mineralizable N was 138.8 µg N and 116.4 µg N/g for Gituamba andosols, 46.0 µg N and 46.4 µg N/g for Kitale ferralsol and 260.1 µg N and 197.3 µg N/g soil for Katumani luvisols in the 0-15 and 15-30 cm depth, respectively. These calculated values compared well with the actual cumulative mineralizable N for Gituamba andosols at 127 µg N and 74.1 µg N/g, for Kitale ferralsols at 48.0 µg N and 64.1 µg N/g and for Katumani 80.6 µg N and 47.7 µg N/g soil in the 0-15 and 15-30 cm depth, respectively.

Table 4. Nitrogen mineralization potential (N_o) mineralization rate constant (k) and *t½* in the three Kenya soils

Soil type	Depth (cm)	N_o µg N/g soil	% TN	Regression coefficient (r)	K week^{-1}	*t½* weeks	Calculated N at 17.1 weeks	Observed cumulative N at 17.1 weeks
Gtuamnba	0-15	392.3	13.2	0.002	0.031	22.3	138.8	124.7
andosol	15-30	162.5	6.1	0.023	0.053	13.1	116.4	74.1
Kitale	0-15	195.6	12.0	0.01	0.023	30.1	46.0	48.0
ferrallisols	15-30	178.7	17.2	0.01	0.027	25.7	46.4	54.1
Katumani	0-15	198.0	12.2	0.022	0.051	13.7	260.1	80.6
luvisols	15-30	75.8	10.0	0.027	0.112	6.3	197.3	47.7

Note. N_o: Nitrogen mineralization potential; TN: Total nitrogen; *t½*: time taken for half of nitrogen to mineralize.

The N_o obtained using Stanford et al. (1974) criteria was 393.3 µg N and 162.5 µg N for Gituamba andosols; 195.6 µg N and 178.7 µg N Kitale ferralsols and then 198.0 µg N and 75.8 µg N/g soil for Katumani luvisols in the 0-15 and 15-30 cm depths, respectively. The mineralization rate constant (k) ranged from 0.023 week^{-1} for Kitale ferralsol 0-15 cm depth to 0.112 week^{-1} for Katumani luvisols 15-30 cm depth. Kitale ferralsols had the lowest mineralization constant of 0.023 and 0.027 week^{-1} in the 0-15 and 15-30 cm depths, respectively. In all soil types, the mineralization rate constant increased with depth. This was 0.031 to 0.053 week^{-1} for Gituamba andosols; 0.023 to 0.027 week^{-1} for Kitale ferralsols and then 0.051 to 0.112 week^{-1} for Katumani luvisols in the 0-15 and 15-30 cm depths, respectively. The time taken for 50% of potentially mineralizable N (*t½*) to be mineralized ranged from 6.3 weeks for Katumani luvisols 15-30 cm to 30.1 weeks for Kitale ferralsols 0-15 cm soil depths. The soils with highest rate constant (k) also had the least *t½*. For example, 15-30 cm depth of Katumani luvisols with *t½* of 6.3 weeks had the highest k of 0.112 week^{-1} compared with Kitale ferralsols 0-15 cm depth with *t½* of 30.1 weeks and the lowest k of 0.023 week^{-1}. The observed data indicates that 50% of N would not be mineralized in the Kitale ferralsols (0-15 cm depth) within the growing period of maize (20 weeks) the major crop grown in the area.

The N_o as % of TN ranged from 6.1 to 17.2% in Gituamba andosols and Kitale ferralsols 15-30 cm depths, respectively. The N_o showed the same trend as %TN and %OC in the three soil types (Table 1) for both depths investigated. There was a positive and significant correlation ($r = 0.82$; $P \leq 0.05$) between % OC and N_o. This positive significant correlation explains the fact that the 0-15 cm depth with higher OM also had higher N_o than the 15-30 cm layer which continues to explain the observed trend in cumulative mineralizable N.

The decline in N_o with depth reflects on the decrease in OM content down the soil profile as seen in all soil types where even actual cumulative N decreased with depth with exception of Kitale ferralsols (Naomi, 2017; Theodore et al., 2005). The difference in N_o in the three soil types could be attributed to the difference in OM contents and the cropping systems in each. Katumani luvisols which had been under cultivation for a long time had lowest N_o especially in the 15-30 cm depth. Gituamba andosols with highest OM content had the highest N_o in both depths.

Actual rates of N mineralization are shown in Table 5. Generally the mineralization rates were higher after 8 week incubation period compared to 17.1 weeks. Again among the three soil types, Gituamba andosols had the highest N mineralization rates of 11 and 7.4 µg N/g/week at 8.6 and 17.1 weeks, respectively. Katumani luvisols had the least and constant N mineralization rates at 2.8 µg N/g/week during both time periods of 8.6 and 17.1 weeks in the 15-30 cm depth. The high substrate in terms of organic matter present in that andosols may have contributed to the observed phenomenon unlike the luvisols where it was lowest. The soil pH and the microbial species and their increased population could also have played a role in the mineralization rate whereby low pH in Gituamba, combined with high organic matter could have maintained N mineralization at a higher and almost steady state. These results concur with the findings of Berendse (1990), and Theodore et al. (2005) who when investigating organic matter accumulation and nitrogen mineralization found that the N mineralization increased with increasing organic matter content in above-ground biomass and litter and in the humus layers.

Soils having higher N_o eventually led to higher amounts of N-mineralization rates (Table 5). For Gituamba andosols, 15-30 cm and Katumani luvisols both depths, half of the N is susceptible to mineralization meaning that it will be mineralized within the growing period of crops. This is so because there *t½* was less than 20 weeks which is the normal growing period of annual crops. For Kitale (both depths) and Gituamba, 0-15 cm depth, this is not the case. However, when the actual mineralized N (48 and 54.1 µg N/g) is compared with calculated N (46.0 and 46.4 µg N/g) for Kitale both depths and 138.8 and 124.7 µg N/g for Gituamba 0-15 cm depths for the 17.1 weeks of incubation, they are more or less the same and therefore validates the use of the formula in these soils.

For Katumani luvisols, very little of the actual N of 80.6 and 47.7 µg N/g soil was mineralized compared to the calculated N at 260.1 µg N and 197.3 µg N/g soil in 0-15 and 15-30 cm depth, respectively. This could be attributed to the very low N content that was initially present and the low OM content in the soil which was not however detected by the formula. It appears therefore that at low OM content in soils, the formula exaggerates the mineralizable N hence cannot be relied on.

The variations in the three soil types could be attributed to soil pH and texture (Theodore et al., 2005; Alizaeh et al., 2012; Waring, 1972) and OM content (Huntjens, 1972; Abbas et al., 2001; Naomi, 20017). The values of N_o in the three soil types ranged from 80 µg N to 392 µg N/g soil while Stanford (1972) obtained values ranging from 20 µg N to 300 µg N/g soil. Herlighy (1979) observed variations in nitrogen mineralization potentials with seasonal changes. He observed the estimates of nitrogen availability based on the nitrogen mineralization potential, N_0, and the mineralization rate constant, k, increased within the sequence, loamy sand, coarse sandy loam and loam, and were consistently higher in the high labile organic matter counterparts of the soils. There was a significant relationship between values calculated from N_0 and k and those obtained near field capacity in the second period of mineralization when soil temperature was relatively constant, but not in the first period when soil temperature was rising (Herlighy, 1979). In his studies, he also observed that the time required for mineralization of 50% of N_0 indicated that less than half the potential value would become available in a normal temperature growing season a phenomenon observed in Kitale ferralsol in the 0-15 cm depth.

Table 5. Actual net N-mineralization rates at 60 and 120 days incubation period in the three soil types (µg N/g/week)

Soil type	Depth (cm)	0 Days (0 weeks)	60days (8.6 weeks)	120 days (17.1 weeks)
Gtuamnba	0-15	-	11.0	7.3
andosol	15-30	-	7.4	4.3
Kitale	0-15	-	4.4	2.8
ferralsos	15-30	-	5.0	3.1
Katumani	0-15	-	5.3	4.7
luvisols	15-30	-	2.8	2.8

4. Conclusions

The nitrogen mineralization potential was highly correlated with %OC. The N_o showed same trend as TN both with depths and soil types. Soils high in %OC and organic N such as Gituamba andosols had also the highest N_o and vice versa. The %OC for Gituamba andosols was significantly correlated ($r = 0.82$, $P = 0.05$) to N_o meaning the higher the %OC the higher the N_o. Soil pH was also negatively correlated to N_o meaning as pH decreased the No increased. The mineralization rate constant (k) ranged from 0.023 to 0.112 week^{-1} while $t½$ ranged from 6.3 to 30.1 weeks. An increase in $t½$ resulted in a decrease in N_o and vice versa. From observed data, it was found that the Stanford formula for predicting N_o is not feasible for soils low in OM content as it tended to exaggerate the mineralizable N. Mineralization rates showed same trend as both total and organic N contents of soil and higher mineralization rates were observed after 60 days of incubation in all depths and in all three soil types. These rates decreased thereafter possibly as the substrate was exhausted.

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