EFFECT OF ORGANIC MATTER AND SOIL FERTILITY ON NITROGEN MINERALIZATION AND ITS UPTAKE BY CASSAVA (*Manihot esculenta* CRANTZ) IN A TYPIC HAPLUDULTS

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Received – March 05, 2015; Revision – March 16, 2015; Accepted – May 21, 2015
Available Online – June 19, 2015

DOI: [http://dx.doi.org/10.18006/2015.3\(3\).232.240](http://dx.doi.org/10.18006/2015.3(3).232.240)

KEYWORDS

Organic matter quality

Soil fertility

N mineralization

N uptake

Typic Hapludults

ABSTRACT

Fertility of soil and crop biomass production are directly affected by organic matters present in soil. The availability of organic matter and its quality plays a key role in the soil, plants and environment sustainability. Present study was aimed to investigate the influence of organic matter and soil fertility on nitrogen mineralization and its uptake by cassava. To estimate the parameters of N mineralization potential (N_0), rate of mineralization (k), and activation energy (E_a) incubation experiments were conducted in the laboratory, using a first order equation. While the relationship between the parameters of N mineralization and nutrient uptake were carried out in green house pot experiments. Value of N_0 , k and E_a were reported 400 - 1156 mg/kg, 0.0056 - 0.098 per week and 10166 - 31478 J mol⁻¹ respectively. N mineralization was positively correlated with water soluble N, N- Particulate Organic Matter, N microbial biomass, C- Particulate Organic Matter, C microbial biomass, N-total plant dry weight, N concentration and N uptake of cassava plants, however it was negatively correlated with C:N ratio. A higher N mineralization rate was found in soils with low C:N ratio of organic matter and higher fertility, as indicated by the value of N_0 , k and $N_0.k$, which were higher than that of high C:N ratio of organic matter and low fertility of soil.

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Peer review under responsibility of Journal of Experimental Biology and Agricultural Sciences.

Production and Hosting by Horizon Publisher (www.my-vision.webs.com/horizon.html).
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1 Introduction

Cassava is one of the most widely cultivated plants in Lampung, Indonesia (Sarno et al., 2004). Planting cassava monoculture in Ultisol may decrease soil fertility, which results in decreasing in soil organic matter, nitrogen (N), and ultimately reduced the yield of cassava (Hairiah et al., 2000). However, addition of organic matter like manure or crop residue in the soil can increase the N and C content in the Cassava cultivated soil (Fließbach et al., 2007). Amongst various nutrient elements, nitrogen is required in higher quantities and it directly influenced the productivity but unfortunately its availability to plants is always in scarcity because of its high mobility within soil. Availability of N in soil is determined by the conditions and the amount of soil organic matter (Cookson et al., 2002). Mineralization is the process of decomposition of organic matter involving microorganisms. It is responsible for the N availability in soil. This process involves the various enzymes which are directly or indirectly involved in the formulation of N compounds in soils and decomposition of manure or protein complex.

This decomposition process was carried out by microorganisms, in this process microorganisms utilized carbon compounds of organic matters and obtained energy. In this process soil organic carbon reduced and as a result of this C:N ratio of the soil get disturbance. The conversion rate of organic N into inorganic N influences the mineralization process and determine the availability of N in the soil. The process of N mineralization consisted of proteins into R-NH₂, ammonification (R-NH₂ to NH₄⁺) and nitrification (NH₄⁺ to NO₃⁻) (Benbi & Richter, 2000). Stanford & Smith (1972) developed a simple exponential equation to describe nitrogen mineralization. This first order kinetic equation can be used to describe the kinetics of N mineralization on the different land-use, crops and climatic conditions (Nishio et al., 1994; Deng & Tabatabai, 2000; Roelcke et al., 2002; Ge et al., 2010; Zhang et al., 2010; Kim et al., 2011). Double exponential model are also widely used to describe the N mineralization, this model contains two parts which describe organic pool having differences in the decomposition of the pool fast and slow (Cartes et al., 2009). In recent years various models based on the logarithmic, parabolic and hyperbolic are also used to determine the rate of N mineralization, among this exponential model is most frequently used by researchers. Microorganism activity is determined by the dynamics of an enzyme that is often described as exponential, so mineralization can also described by this exponential models (Li et al., 2003). Several kinetic models are often used together to predict the kinetics of N mineralization followed by selection of a model that can describe the process of kinetics is based on the highest correlation coefficient with the lowest standard error (Shariatmadari et al., 2006).

Determination of the soil chemical properties that affects the kinetics of N mineralization in the soil is crucial to improve the

crops productivity. Watanabe et al. (1996) and Inubushi et al. (1985) has been reported a negative correlation between clay content and k value in paddy soil. Furthermore, N₀ values positively correlated with water-soluble C. In dry soils, the value of N₀ is positively correlated with organic N extracted by phosphate buffer extraction ($r = 0.66^{**}$, $P < 0.01$) and sulfuric acid extract ($r = 0.69^{**}$, $P < 0.01$) (Sano et al., 2006). However, in peat soils, N₀ value is negatively correlated with the ratio C alkyl to O-alkyl C (Purwanto et al., 2006). Similarly, wide range of k values shows differences in the availability of active organic N and microbial activity. Many studies of N mineralization were related to the chemical properties of soil, but still they are rarely associated with N labile or C labile fractions in the soil. Fractions of N labile and C labile are important source of energy for microorganisms which plays important role in the mineralization process. Light fractions are transit pool between fresh organic and humified organic, contributing to reserve of C organic and energy sources for microorganisms (Haynes, 2000; Burton et al., 2007; Laik et al., 2009). A labile organic matter fraction has a significant effect on soil organic matters reserve. A change in the quantity of these fractions is an early indicator to predict the effect of mineral application land and soil management (Soon et al., 2007; Lou et al., 2011). The sufficiency of nutrient availability in the soil is important to support the growth and high crop production. Nutrient uptake by plants depends on the concentration of nutrients in the soil. N nutrient availability in the soil is influenced by the rate of mineralization of organic matter, so it is necessary to learn the relationship between N mineralization kinetics parameters and the availability of N and N uptake by plants.

2 Materials and Methods

2.1 Soil Preparation and Experimental Treatment

Soil used for experimentation were taken from a depth of 0-20 cm (topsoil) belonging to Typic Hapludults order (ICALRD, 2008). The results pertaining to soil analysis are presented in Table 1. Experiment was laid down in completely randomized design. Two factors viz land use and types of organic matters were studied in detail. First factor land uses was divided in the subcategories like collection of soil under cassava cultivation less than 10 years and more than 30 years while the second factor was the type of organic matters it consists of various biomasses like only groundnut; only maize; combination of groundnut-maize (in 1:1; 2:1 & 1:2 ratio) and control (without organic matter). All the selected biomasses were applied @ level of 5t/ha. The soil of the experimental field sieved through 2 mm sieve. 10 g of soil was weighed and kept into a plastic bottle which was followed by its treatment with organic matter. The moisture content of the soil was maintained at field level. These bottles were stored in an incubator at the temperature of 20°C, 25°C and 30°C. After 0, 2, 4, 8, 6, 10 and 12 weeks of observation, content of N (NH₄⁺ and NO₃⁻) determined following Kjeldahl method with extracts of 1 M KCl.

Table 1 Analysis of experimental soil for various chemical properties.

Soil Properties	Soil planted with cassava less than 10 years	soil planted with cassava more than 30 years
pH (H ₂ O)	5.1	4.6
N (%)	0.073	0.037
Organic C (%)	2.06	0.70
P-Bray 1 (ppm P ₂ O ₅)	15.9	6.8
CEC (cmol (p+) kg ⁻¹)	6.54	4.12
K (cmol (p+) kg ⁻¹)	0.14	0.05
Ca (cmol (p+) kg ⁻¹)	1.68	0.50
Mg (cmol (p+) kg ⁻¹)	0.33	0.15
Al exchange (cmol (p+) kg ⁻¹)	1.40	2.50

The relationship between N mineralization kinetics and nutrient uptake were obtained by treating cassava in the greenhouse, experimental condition were similar to incubation experiment. Plants grown in pots contained 15 kg of soil at field capacity. Plants harvested at the age of 4 months and analyzed for the N uptake. Soil of experimental plots were analyzed for 'C and N microbial biomass', 'C and N water-soluble', 'C and N Particulate Organic Matter (C, N POM) after plant harvested (Soon et al., 2007; Okore et al., 2007).

2.2 Kinetics of Nitrogen Mineralization

Kinetics of nitrogen mineralization was predicted by mineralization potential (N₀ in mg kg⁻¹), mineralization rate constant (k on day⁻¹), apparent activation energy (E_a in J mol⁻¹) and using a simple reaction type models developed by Sugihara et al. (1986):

$$N = N_0 [1 - \exp(-kt)] \quad (1)$$

Here N is the number of inorganic N (mg N kg⁻¹) on day t, N₀ is the potential mineralization (mg kg⁻¹), k is the rate constant of mineralization (day⁻¹).

Determination of activation energy (E_a, J mol⁻¹) was carried out by using two temperatures T₁ and T₂ and k₁ and k₂ with the help of method described by Kanda (2000).

$$E_a = R / (1/T_1 - 1/T_2) \cdot \ln(k_1/k_2) \quad (2)$$

R is the gas constant (8318 J K⁻¹ mol⁻¹)

The formula as outlined by Kanda (2000) was followed for estimating minimum incubation time (T_m):

$$T_m = 0.76 / k \quad (3)$$

dfQ10 values (Arrhenius models) by using temperature as constant referent by comparing N mineralization (Guntinas et al., 2012) :

$$Q_{10} [(T-T_1) / 10] = k/k_1 \quad (4)$$

Where T is temperature, T₁: referent temperature (20°C), k: constant at temperature T, k₁: constant temperature T₁.

The data analysis of N mineralization uses first-order kinetics equation fitted with the curve fit procedure using the program SigmaPlot 12 (SYSTAT software inc, 2011).

3 Results and Discussion

3.1 Nitrogen mineralization during incubation

Application of groundnut and maize biomass had a positive effect on nitrogen mineralization. Combination of groundnut & maize biomass (2:1) showed highest N mineralization (Table 2). Application of organic matter derived from groundnut biomass could reduce the original C:N ratio of organic matter derived from maize biomass.

The low C:N ratio of organic matter causing susceptibility towards mineralization. Results of the present study shows similarity with the finding of Singh et al. (2007) those have reported that mixing low C:N ratio of organic matter derived from Sesbania (16) and the high C:N ratio derived from wheat straw (82) has increased N mineralization. The C:N ratio is often used to predict rate of N mineralization, results of the previous studies clearly indicated that use of different C: N ratio showed the breakeven point between mineralization and immobilization occurs at C:N ratio around 21 (Hadas et al., 2004).

Soil fertility has effects on the amount of N released during the mineralization process. The mineralized of N was reported higher in the soil that planted with cassava less than 10 years than the soil planted with cassava more than 30 years. Soil planted with cassava less than 10 years, amount of cumulative N was 1086 mg kg⁻¹, while the soil that planted with cassava more 30 years, the amount of N released was 783 mg kg⁻¹. The value of pH, N, organic C, P and exchangeable bases were found higher in soil under less than 10 years cassava cultivation as compared to the soil under more than 30 years cassava cultivation. Gonzalez-Prieto et al. (1992) reports that mineralization was negatively correlated with exchangeable aluminum, hydrogen, and available Fe. Increased soil pH will increase N mineralization (Li et al., 2003).

Table 2 Cumulative nitrogen mineralization (mg kg⁻¹) for 12 weeks at various temperatures and biomasses application.

Treatments	20°C	25°C	30°C
Soil that planted with cassava less than 10 years			
Only Groundnut (G)	550.6	773.8	1015.6
Only Maize (M)	435.2	704.9	872.3
G : M (1:1)	533.8	943.0	1036.0
G : M (2:1)	589.6	1011.8	1086.2
G : M (1:2)	459.4	710.5	851.9
Control (Without Organic Matter)	347.8	459.4	450.1
Soil that planted with cassava more than 30 years			
Only Groundnut (G)	496.6	738.4	747.7
Only Maize (M)	388.7	556.1	638.0
G : M (1:1)	444.5	634.3	638.0
G : M (2:1)	526.4	738.4	783.1
G : M (1:2)	375.7	647.3	758.9
Control (Without Organic Matter)	264.1	437.1	394.3

Temperature has positive effect on N mineralization and it was well reported that higher temperature shows higher rate of N mineralization. In all treatments, N mineralized at 30°C temperature was reported higher than the other temperatures under observation, although it is not significantly differing than N mineralized at 25°C (Table 1). According Nicolardot et al. (1994) and Stark & Firestone (1996), maximum N mineralization takes place between the temperature range of 25-35°C.

3.2 The rate of mineralization (k), N potential (N₀) and Q₁₀

Effect of the application of organic matter derived from groundnut and maize biomass affect the mineralization rate constant (k). The rate of mineralization (k) in soil under cassava cultivation less than 10 years and more than 30 years shows almost similar pattern. Among the various biomass tested, application of organic matter derived from groundnut : maize biomass (2:1) has highest k value this value was followed by the application of individual groundnut, groundnut : maize combination (1:1), groundnut : maize combination (1:2), individual maize and control without organic matter respectively (Table 3). Findings of the present study indicated that the mixing of organic matter with groundnut having low C:N ratio while the maize biomass has high C:N and because of this groundnut shows higher rate of mineralization as compared to maize. Result of the present study are in agreement with the finds of Sholihah et al. (2012) those who have reported that the rate of mineralization indirectly correlates with the ratio C:N (0.582*), which shows that higher mineralization take place at low C:N (Abera et al., 2012). The observation of N potential also shows the similar pattern of the rate of mineralization.

A positive correlation has been reported between the rate of mineralization constant (k) and temperature. The value of k

has increased around 32% by increasing temperature from 20-30°C for the soil under cultivation of cassava less than 10 years, while the soil under cultivation of more than 30 years of cassava cultivation has about 27% higher k value at the same temperature. Findings of the present study are in conformity with the findings of Guntinas et al. (2012) those have reported that the value of k is strongly influenced by temperature and sharply increased between 25°C and 35°C. Increased value of k at higher temperature is attributable to faster decomposition of organic matter (Nordmeyer & Richter, 1985). This is due to the changes in the biochemical composition of organic matter, changes in transport processes such as diffusion processes that affected the temperature and increasing the number of microbes (MacDonald et al., 1995). Highest k value (0.098) was reported for the combination of groundnut : maize (2:1) in the soil planted with cassava less than 10 years. While this value was reported 0.0083 for the same treatment in the soil planted with cassava more than 30 years. Low k values can be assumed that the activity of soil microorganisms is also low (Nira & Nishimune, 1993). The soil with low organic matter, low microbial population shows poor N mineralization (Nishio et al., 1994).

Q₁₀ value is the representation of the rate of biological or chemical changes in soil at every 10°C increases. Rodrigo et al. (1997) and Hartley & Ineson (2008) recommended that the use of Arrhenius models with reference temperature i.e. 20°C is the best way to compare the soil variations (Table 3). For the present study the values of Q₁₀ were reported normal for all the treatments. Similar type of study was conducted by Kirschbaum (1995) and reported average Q₁₀ value between 1.10-1.93 at 30°C. The difference in the Q₁₀ value is generally caused by differences in the composition of organic matter, state of research and range of temperatures used (Rodrigo et al., 1997).

Table 3 Effects of groundnut and maize biomass application on the value of k (per week), N mineralization and Q_{10} value at various temperatures range in the Typic Hapludults.

Treatments	20°C			25°C			30°C			Q ₁₀
	k	N0	R ²	k	N0	R ²	k	N0	R ²	
Soil under cassava cultivation in less than 10 years										
Only Groundnut (G)	0.0064	693.5	0.992	0.0070	703.9	0.997	0.0090	743.0	0.996	1.41
Only Maize (M)	0.0061	560.5	0.986	0.0069	848.1	0.993	0.0074	989.8	0.989	1.21
G : M (1:1)	0.0064	673.6	0.991	0.0077	979.8	0.995	0.0090	1000.9	0.995	1.41
G : M (2:1)	0.0067	725.8	0.987	0.0074	1248.1	0.993	0.0098	1150.5	0.994	1.46
G : M (1:2)	0.0060	621.1	0.988	0.0063	722.0	0.997	0.0078	1056.2	0.989	1.30
Control (Without Organic Matter)	0.0056	400.2	0.967	0.0060	560.4	0.990	0.0063	641.1	0.966	1.13
Soil that planted with cassava more than 30 years										
Only Groundnut (G)	0.0058	660.3	0.984	0.0077	676.7	0.997	0.0080	587.5	0.996	1.37
Only Maize (M)	0.0056	518.6	0.985	0.0057	784.8	0.981	0.0067	825.9	0.990	1.19
G : M (1:1)	0.0057	635.9	0.975	0.0072	709.2	0.995	0.0076	650.7	0.997	1.33
G : M (2:1)	0.0060	718.2	0.983	0.0074	828.2	0.996	0.0083	1057.8	0.998	1.38
G : M (1:2)	0.0060	494.1	0.988	0.0068	787.2	0.993	0.0072	994.1	0.982	1.20
Control (Without Organic Matter)	0.0051	400.2	0.967	0.0052	706.8	0.972	0.0058	544.7	0.981	1.14

3.3 Activation energy and the incubation time

Like other factors activation energy is also influenced by the type of available organic matter and land uses. Among the various tested biomasses highest activation energy was reported from the treatment containing the combination of groundnut : maize biomass in the soil that used for cassava plantation from less than 10 years. For the soils planted with cassava less than 10 years, the activation energy was reported between the 10166 J mol⁻¹ (no organic matter) - 31478 J mol⁻¹ (groundnut:maize, 2:1), whereas, this value was reported between 10899 J mol⁻¹ (no organic matter) - 26791 J mol⁻¹ (groundnut: maize, 2:1) for the soil planted with cassava more

than 30 years (Table 4). According to Purwanto et al. (2006) value of activation energy is correlated with the temperature and higher activation energy was reported at the higher temperature. Furthermore, activation energy is also associated with the incubation time and higher activation energy was reported at the minimum incubation period. The greater the activation energy, shorter will be the minimum incubation time. Minimum incubation time ranged from 77-120 days in the soil under less than 10 years of cassava cultivation, while for the soil under cassava cultivation more than 30 years cassava shows incubation period between 91-131 days (Table 4). Combination of maize and groundnut biomass shows minimum incubation time.

Table 4 Effects of the various biomasses on the activation energy and incubation time in the Typic Hapludults.

Treatments	Activation energy (J mol ⁻¹)	Period of incubation (days)
Soil that planted with cassava less than 10 years		
Groundnut (G)	28580	84.4
Maize (M)	15856	102.7
G : M (1:1)	28580	84.4
G : M (2:1)	31478	77.6
G : M (1:2)	10166	97.4
No organic matter	10166	120.6
Soil that planted with cassava more than 30 years		
Groundnut (G)	26186	95.0
Maize (M)	14469	113.4
G : M (1:1)	23721	100.0
G : M (2:1)	26791	91.6
G : M (1:2)	15166	105.6
No organic matter	10899	131.0

Table 5 The coefficient of determination (R^2) between N mineralization kinetics parameters (N_0 , k , and $N_0.k$) with the labile N fraction, C labile, total N, total C and C:N ratio.

Observations	N_0	k	$N_0.k$
N water soluble (%)	0.585**	0.563**	0.632**
N-POM (%)	0.643**	0.482**	0.650**
N Microbiomass (mg kg⁻¹)	0.390*	0.286	0.405*
C water soluble (%)	0.014	0.056	0.001
C-POM (%)	0.522**	0.489**	0.544**
C Microbiomass (mg kg⁻¹)	0.453**	0.388*	0.499**
C (%)	0.145	0.141	0.179
N (%)	0.608**	0.453**	0.697**
C/N ratio	0.487**	0.453**	0.534**

* significant at $P < 0.05$, ** significant at $P < 0.01$

Table 6 The coefficient of determination (R^2) between N mineralization kinetics parameters (N_0 , k , and $N_0.k$) with plant dry weight, N concentration and N uptake.

Observations	N_0	k	$N_0.k$
Plant dry weight	0.519**	0.458**	0.621**
N uptake	0.539**	0.586**	0.716**

* significant at $P < 0.05$, ** significant at $P < 0.01$

3.4 Relationship between N mineralization kinetics parameters with labile fractions

The correlation coefficient between N mineralization kinetics parameters with labile C, labile N, organic C, total N and C:N ratio are presented in Table 5. N_0 and $N_0.k$ positively correlated with water-soluble N, N-POM, N microbial biomass, C-POM, C microbial biomass C, N-total and negatively correlated to C:N ratio. Results of Sano et al. (2006) on dry soil recommended that the value of N_0 is positively correlated with water soluble N (0.66 **), water-soluble C (0.76**), total N (0.29*) and total C (0.26*). Furthermore, Sano et al. (2006) suggested that the value of N_0 is an index of long-term N mineralization, whereas value $N_0.k$ is an index short-term mineralization. The results of this study indicated that the both value of N_0 and $N_0.k$ were positively associated with soluble N, N-POM, N microbial biomass, C-POM, C microbial biomass, N-total and negatively correlated with C: N ratio (Sano et al., 2006). Present study showed that the fraction of labile N contributed more to the mineralization process. In the soils, number of N labile fraction is relatively low. Addition of organic matter can make decomposition process relatively easier, because labile N fraction is a source of N mineralized (Sano et al., 2006).

3.5 The relationship between the parameters of N mineralization kinetics and N uptake

The parameters of N mineralization kinetics positively correlated with plant dry weight, and N uptake (Table 6). So, N mineralization kinetics can be used to estimate N nutrient uptake by plants. The higher value of N_0 and k favor the N mineralized from organic matter. The addition of organic

matter in the soil will increase the activities of microorganism which increased the process of mineralization especially increased the addition of N and C in soil (Table 5). It has been reported that increase in the value of the N_0 , k and $N_0.k$ increase the N mineralization kinetics which is closely linked to the availability of N in the soil, resulting in increased N uptake by plants. Microorganism can use various sources of N through the life cycle.

By the process of organic matter decomposition, microorganisms will release N directly into the soil or microbes can be use it for the purposes of their own growth and then releases it into the soil through the process of secretion (Geisseler et al., 2009). Yan et al. (2006) reported that N mineralization was positively related to N uptake in rice. The treatment without N fertilizer showed approximately 98% of N absorbed by rice was from N mineralization. .

Conclusion

Soil fertility effects N mineralization and it was higher for the soil under cassava cultivation less than 10 years while this process is slower in the soil planted with cassava more than 30 years. Mineralization rate constant (k) is also affected due to temperature. Increasing k from 20°C to 30°C on soil planted with cassava less than 10 years was around 32%, while it was 27% on soils that were planted with cassava more than 30 years. The parameters of N mineralization (N_0 and $N_0.k$) were positively correlated with water-soluble N, N-POM, N microbial biomass, C-POM, C microbial biomass, N-total, plant dry weight, N concentration in leaf and N uptake. N mineralization parameters are important to estimate N uptake by cassava plants.

Conflict of interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

Acknowledgments

The authors gratefully acknowledge to The Board of Agricultural Research Development, Ministry of Agriculture, Indonesian for the financial support and the authors wish to thank the Laboratory staff of ILETRY to provide facilities for the achievement of this research.

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