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Aerobic mineralization of selected organic nutrient sources for soil fertility improvement in cambisols, Southern Ethiopia

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Application of organic nutrient sources ONS for soil amendment may have an enormous advantage that improve nutrient cycling in soil–plant relations. The amount and rate of nutrient release from plant residues depend on their quality characteristics and biochemical composition of the ONS. An Aerobic Mineralization study was conducted in green house experiment to determine the N release dynamics of *Erythrina abyssinica* (EA), *Erythrina brucei* (EB) and *Ensete ventricosum* (EV) (ONS) were randomly collected from Wolaita and Sidama zone of Southern Ethiopia. Surface soil samples (0-20 cm) depths were also collected from Cambisol of Wolaita. Physicochemical properties of the composite soil were analyzed following standard analytical methods. For the greenhouse aerobic mineralization pot experiment, four treatments were designed for EA, EB and EV and control in Cambisols. The incubation was carried out for five consecutive weeks. The treatments were arranged in a completely randomized design (CRD) with three replications. The results of mineralization revealed that the NH_4^+ concentration was highest in the first week and became almost equal to the concentration of NO_3^- in the second week, and then it became low and constant at the third to fifth week. While the concentration of NO_3^- was low in the first week, it became equivalent to the concentration of NH_4^+ in the second week, and became higher and constant at the third to fourth week after which it started declining. The organic carbon and total nitrogen were also following the same trend. In general, these ONS had medium to high TN content and they decomposed easily. Thus, they can be used as alternative or supportive organic sources. In their first week of decomposition they furnished NH_4^+ and from third week on wards they are good for NO_3^- loving crops, while the second week of mineralization is good for crops loving both inorganic forms of nitrogen. The present study indicates incorporation of EA, EB and EV modifies the fertility of cambisols and shall be taken into account to synchronize between net N mineralization and crop demand. However, more detailed research and field experimentations are needed on decomposition in some other soil types to draw sound conclusions.

Key words: Ammonium, incubation, mineralization, nitrate.

INTRODUCTION

Reduced agricultural productivity per unit of land and inadequate knowledge of soil fertility maintaining sources, such as balanced nutrient application, soil conservation and good fertility management within fields have been reported to contribute to low soil fertility in Sub Saharan Africa (Vanlauwe and Giller, 2006; Amede and Taboge, 2007; Edwin et al., 2012).

The use of organic farming techniques to grow crops, fruits and vegetables have increased popularity in recent years as a result of both an increase in consumer demand and awareness for organically grown products and a genuine desire on the part of many farmers to sustain or improve the soil quality and maintaining soil health (Dimitri and Greene, 2002).

Nevertheless, addition of ONS as soil amendments is a vital management strategy that can amend and improve soil-quality parameters and modify the nutrient cycling through mineralization or immobilization (Novara et al*.,* 2013; Baldi and Toselli, 2014; Hueso-G et al*.*, 2014).

Several studies have shown that green manure and leguminous trees could improve soil fertility and increase crop yields depending upon the decomposition rates and synchrony of nutrient mineralization (Drechsel and Reck, 1998; Ng'inja et al., 1998; Sileshi et al*.*, 2008; Murungu et al*.*, 2011). For instance, *Erythrina brucei* (EB), leguminous tree, biomass (5-10 tons ha^{-1}) incorporated into the soil have increased the wheat grain yield by 82-127% over the control (Wassie et al*.,* 2009). Inorganic materials released during this process are the essential chemical products that are required by plants for further food synthesis (Lavelle and Spain, 2001).

Multipurpose trees such as *Erythrina abyssinica* (EA), *Erythrina brucei* (EB) and *Ensete ventricosum* (EV) potential organic fertilizers are found in the homestead of most farmers of southern Ethiopia. They are used as fences, wind break and are used to maintain soil health through their decomposition (Thulin, 1989; Fassil, 1993; Demil, 1994; Legesse, 2002).

The benefit of applying ONS amendments has become thought-provoking subject of investigation, not only for their importance in soil functioning and structure, but also because of changes they made in soil chemical and physical properties, such as enhancing biological activity, improving physical properties, increasing nutrient availability, improving water infiltration, decreasing evaporation, and increasing water-holding capacity of soils (Fliessbach et al., 1994; Kumar and Goh, 2000; Palm et al*.,* 2001; Sasaki et al., 2009; Saleem et al*.,* 2013).

Hence, further investigation on ONS for improving soil fertility is a crucial step for low-income farmers, and organic manure advocators. Studying the nutrient release pattern of ONS such as of *E. abyssinica, E. brucei* and *E. ventricosum* is important for the synchronization of nutrients released with crop demand which ultimately helps to decide when and how much ONS to apply under specific soil and environmental conditions in order to optimize the induced soil nutrient availability to crop demand.

The objective of this investigation was to evaluate the mineralization rates of EA, EB and EV to release of ammonium, nitrate and decomposition of organic carbon and total nitrogen, the weeks required mineralize as well as to study the effect of these ONS on selected physicochemical properties of cambisols.

MATERIALS AND METHODS

Plant sampling site description

The ONS samples were collected from Wolaita zone in Southern Ethiopia. Its altitude ranging from 1200 to 2950 m.a.s.l. with annual average temperature of 15.1°C and the mean annual rainfall ranges from 1200 to 1300 mm. The area has a bimodal rainfall pattern, with an average annual rainfall of 1300 to 2000 mm distributed over 8 to 9 month (SNNPR, 2008).

Plant sampling and preparation

Samples of *E. brucei and E. ventricosum* were collected from five different randomly selected locations of the Wolaita zone, *E. abyssinica* was collected from nearby zone (Sidama) but all samplings were georeferenced. Soil color differences were observed (biases) during plant sampling. Representative leaves (old and new) and twigs were sampled from randomly selected *E. abyssinica, E. brucei* and *E. ventricosum* plants. These plants were washed thoroughly with tap water and rinsed with distilled water, followed by first air-drying and then oven drying at 65°C for 24 h before grinding by mortar and pestle to pass through 1 mm sieve.

Procedure of soil sampling

Representative surface soil was collected from Cambisols of Wolaita as characterized by Ashenafi et al. (2010). About 5 kg surface soil samples (0-30 cm depth), was collected using auger from 30 different randomly selected spots to make, one composite sample. The sample was used for chemical and physical analysis and greenhouse experiment. The portions of composite samples to be used for pot trial in the green house experiment was homogenized, disaggregated and crushed, while for physicochemical analyses sub samples was taken and air-dried and ground with mortar and pestle to pass through a 2 mm sieve except for organic carbon and total nitrogen determinations, in which the sample had further ground to pass a 0.5 mm sieve.

Selected soil physical and chemical analyses

Soil pH and electrical conductivity were measured using soil: water (1:2.5) according to, Reeuwijk (2002). Organic carbon and total N

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Table 1. Selected chemical and physical characteristics of the soil.

Parameter	Unit	Result
Depth	CM	0-20
pH-H_20	1:2.5 ratio	6.27
EC	dSm^{-1}	0.064
OC	%	1.52
TN	%	0.13
C/N		12
Av.P	mg kg^{-1}	3.92
FC	V %	42.74
PWP	V %	27.57
BD	Mgm^{-3}	1.23
sand	%	16
Silt	%	36
Clay	%	48
Textural Class		Clay

content in the soil were determined using Walkley and Black, (1934) method and modified Kjeldahl procedure (Nelson and Sommers, 1980) respectively. Mineral N was extracted at a ratio of 1:4 (soil: 2M KCl), according to Keeney and Nelson (1982). For soil particle size analysis hydrometer method (Bouyoucos, 1951) was employed. The soil moisture contents at field capacity (FC,-0.3 bars) and at permanent wilting point (PWP,-15 bars) were measured by the pressure plate apparatus. Finally, the plant available soil water holding capacity was determined from the difference between water content at FC and PWP (Hillel, 1980).

Description of the experimental site

The mineralization study was conducted at Hawassa. It is situated at 07° 03' North and 38° 29' East with an average altitude of 1750 m.a.s.l. According to the National Meteorological Agency, Hawassa Branch Directorate (NMAHBD) (2009), the climate is warm with mean temperature varying between 10°C in the winter and 30°C during the summer months. The area receives the mean annual precipitation of 956 mm, with monthly mean minimum rainfall of 17 mm in December (dry season) and mean maximum of 126 mm in September (main rainy season). During the mineralization experiment the monthly average minimum temperature ranged from 11.7 to 13.5°C, and the monthly average maximum temperature ranged from 30.7 to 31.8°C, according to NMAHBD (2012).

Incubation of soil samples

The incubation experiment was conducted at Hawassa University. Based on the plant analysis result, the weight of plant sample to be incorporated was selected and calculated by making equivalent recommendation for wheat, 100 kg ha^{-1} urea and 100 kg ha^{-1} DAP in the region (personal communication). The soil sample was weighed (200 g) and mixed with the air dried plant sample followed by fully homogenizing with 0.124 g of *E. abyssinica,* 0.149 g of *E. brucei* and 0.206 g of *E. ventricosum*. Then it was transferred into 300 mL wide mouth pp bottle. Each pot was sampled separately at 1, 2, 3, 4, and 5 week stages. Each sample was mixed thoroughly, quartered and one quarter was transferred to the laboratory in a labeled bag for analysis. The soil and organic nutrient resource mixture was watered to field capacity by monitoring with Moisture Meter (Delta, model HH2). Then, the samples which were ready (mature for the test) for analyses were collected and transferred to chemical laboratory for further analysis.

Data analysis

The data obtained from the analyses of plants and mineralization were subjected to analysis of variance (ANOVA) using statistical analysis software version 9.3 (SAS 2003). The Duncan multiple range test ($P< 0.05$) was worked to separate means among treatments. Simple correlation analysis was carried out to measure release of nutrients (NH_4^+ and NO_3^-, and Organic carbon and Total Nitrogen) in soil.

RESULTS AND DISCUSSION

Selected soil physico-chemical properties

The soil texture of Wolaita was found to be clayey (Table 1). The critical bulk density value for agricultural use according to Hillel (1980) is 1.4 g cm^{-3}. Thus, the soil had lower value than the critical value; implying that there is no excessive compaction and restriction to root development (Werner, 1997). This soil possesses good porosity for activities of aerobic microorganisms. The pH-H_2O value of the soil was 6.2. According to the rating of Kim (1996) the pH range of the soils was slightly acidic.

The Cambisols of Wolaita is favorable for microorganisms' population growth. The OC contents of the soils fall in the "very low" range according to Landon (1996) rating. The TN content of soil is categorized under the "low" category, according to Landon (1996) rating.

Total nitrogen content of EB and EV with respect to location

The TN content of *E. brucei*, ranged from 3.93% (highest) at Kokate to 2.77% (lowest) at Shone. The TN values of EV ranged from 1.18% (lowest) at Delbo Atwero to 3.03% (highest) at Gacheno. Even though the TN content of EB, in some places exceeded the highest rating level by Chapman (1966), the TN content of EB at the study site (mean of mean 3.36% TN) can be rated as medium in terms of nitrogen fixation as outline by Jones, (1998) who described that nitrogen constitutes 1.5 to 6.0% of the dry weight of many crops (Table 2).

The results obtained in this study depicts that the overall mean of mean TN content of EV were (2.42 %) and can be categorized in medium range, as low nitrogen containing plant, as compared to the common organic sources such as pigeon pea fresh leaves (3.24%), pigeon pea litter (1.63%), and Sesbania (3.44%) (Eghball, 2000).

Table 2. TN content (%) of EB and EV collected at different sites and altitudes.

Site	Altitude (m.a.s.l)	*Erythrina brucei* TN (%)	*Ensete ventricosum*
Delbo Atwero	2236	3.85[a] (3.77-3.93)	1.18[d] (1.16-1.23)
Doga	1975	3.38[b] (3.31-3.47)	2.75[b] (2.62-2.85)
Gacheno	1884	2.85[c] (2.70-3.00)	3.03[a] (2.93-3.16)
Kokate	2154	3.93[a] (3.91-3.94)	2.57[c] (2.46-2.62)
Shone	1996	2.77[c] (2.70-2.85)	2.54[c] (2.70-2.85)
CV (%)		2.71	3.89

Values in brackets show ranges, Means in a column followed by the same letters are not significantly different.

Table 3. Interaction effect of EA, EB, EV and weeks of incubation on NH_4^+.

Week	CO	EA	EB	EV
1	1.30[h]	4.77[a]	3.42[b]	2.20[e]
2	1.20[i]	2.72[c]	2.50[d]	1.75[g]
3	0.50[m]	1.78[f]	1.01[j]	0.83[k]
4	0.50[m]	0.51[m]	0.51[m]	0.60[l]
5	0.50[m]	0.51[m]	0.50[m]	0.52[m]
	CV (%)	1.30		

Means in a column followed by the same letters are not significantly different at p≤0.05.

The average (4.2%) TN content of EA in Sidama zone was greater than those reported by Wilkson and Festus (2008) in Zomba, Malawi, i.e. 3.44 and 2.89% TN for Sesbania and Gliricidia, respectively**.** The variation in TN content of EA, EB and EV in different sites could be due to cumulative contribution of micro agro climatic factors: soil fertility, temperature, and microorganism (Hodge and Storer, 2015), in addition to the differences in altitude. In Wolaita zone, the existence of different soil orders might have contributed to the difference in percent TN content of the ONS (Mulugeta, 2006).

Mineral N release from EA, EB and EV in Cambisol

NH_4^+*-N release*

NH_4^+-N is the initial by-product of organic N mineralization. The interaction among ONS, and week were significant. The amount of NH_4^+-N released from the ONS differed significantly at each sampling week. During the mineralization process of ONS a negative and high correlation. ($r = -0.771$, $p \leq 0.0001$) were observed between NH_4^+ and Week of incorporation. At the first incubation period (week), the highest release of NH_4^+-N (4.77 mg kg^{-1}) was recorded from EA incorporated into Cambisol. However, a positive and high correlation ($r = 0.943$, $P < 0.0001$) with organic carbon and ($r = 0.619$, $P < 0.0001$) with Total Nitrogen were found between released NH_4^+-N and decomposition of the ONS.

The lowest release of NH_4^+-N (0.497 mg kg^{-1}) was recorded from EB incorporated to the soil at the 5th week. However, the laboratory results revealed that there was general decreasing trend in the release of NH_4^+-N as weeks went on (Table 3). The probable reasons for decrease in mineralization of these organic nutrient sources could have difference in residue quality, and as a result decrease in microbial activity (Trinsoutrot et al., 2000). Secondly, legume residue decomposition and nutrient release rates are influenced by legume quality parameters such as N, polyphenol, and lignin contents and their ratios (Tian et al., 1992; Giller and Cadisch, 1997; Abebe et al., 2015). The faster NH_4^+ release performance of EA can be accounted for its highest TN content. Inline to this, a study carried out by Kaleeem M. et al., (*2015)* also presented similar conclusion on Shoots of *Glycine max* and *Trifolium repens* and leaves of *Robinia pseudoacacia* and *Elaeagnus umbellate* in Pakistan.

Indeed, though the levels of accumulated NH_4^+ varied among weeks, ONS and incubation periods, the soil showed periodical mineralization when amended with ONS. The NH_4^+-N content was in the order EA > EB> EV in Cambisol suggesting that the soil was more

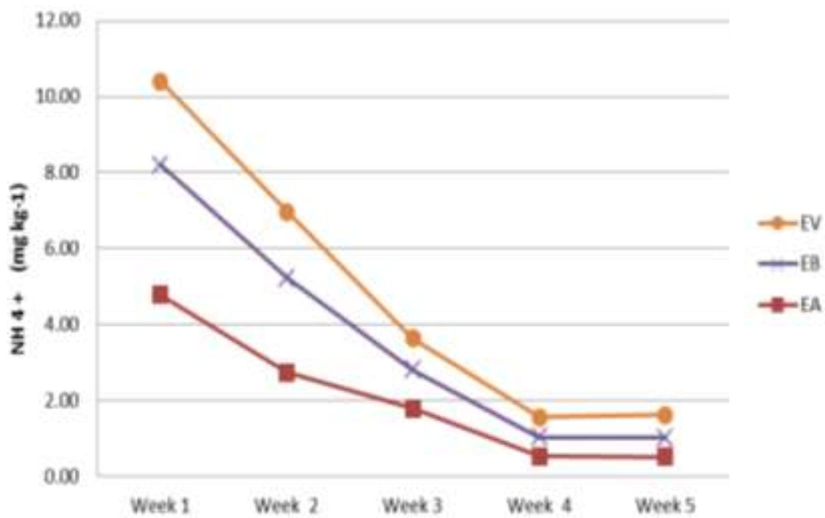

Figure 1. Weekly NH_4^+ mineralization of EA, EB and EV in Cambisols of Wolaita.

Table 4. Interaction effect of EA, EB, EV and (incubation) Weeks in Cambisol and NO_3-.

Week	CO	EA	EB	EV
1	1.10 ^{i}	1.73^{g}	1.83^{f}	1.41^{h}
2	1.11 ^{i}	2.62^{c}	2.44^{d}	1.71^{g}
3	1.11 ^{i}	3.12^{a}	2.81^{b}	2.60^{c}
4	1.11 ^{i}	3.10^{a}	2.83^{b}	2.57^{c}
5	1.11 ^{i}	2.87^{b}	2.58^{c}	2.20^{e}
	CV (%)	2.16		

Means in a column followed by the same letters are not significantly different.

responsive to decomposition of organic nutrient source. The highest values were observed in amended over non amended (control) soil samples. The pronounced effect as described by Brussaard and Juma (1995) could be due to available food source for soil organisms.

Moreover, there were significant differences between the release of NH_4^+–N and the organic nutrient type (Figure 1). The studies conducted by Rochette et al. (2000) and Vahdat et al. (2011) had shown that organic sources which contain labile C pool (organic acids, amino acids, and simple sugars) could be rapidly mineralized than the non-labile pool. Physical accessibility for microbes may also be an important determinant of decay rate (Fyles and McGill, 1987).

NO_3^- *-N release*

During the incubation period, the mineralization of EA, EB and EV in the soil, revealed that their initial NO_3^- were affected by mineralization and nitrification process (Table 4 and Figure 2). In the decomposition of EA, EB and EV positive and week correlation (r =0.345, P ≤ 0.0001) was found between period of incubation (weeks) and NO_3^-- N release, indicating that there was weak association of weeks incubation and release of NO_3^--N. The incubation experiment indicated that the highest increase in NO_3^- content was obtained from EA, EB and EV, which contains 3.12, 2.83 and 2.60 mg kg^{-1} in the third , fourth and third weeks respectively. The lowest release was in the order of EB > EA> EV at an amount of 1.83, 17.33 and 1.41–mg kg^{-1} in first week, respectively (Table 4). The NO_3^- release was slow in the first week and then increment was observed in the nitrate content of the soil (same trend was followed by all the three ONS amendments). Moreover, nitrification was significantly and positively correlated with ONS (r = 0.428, P ≤ 0.0001).

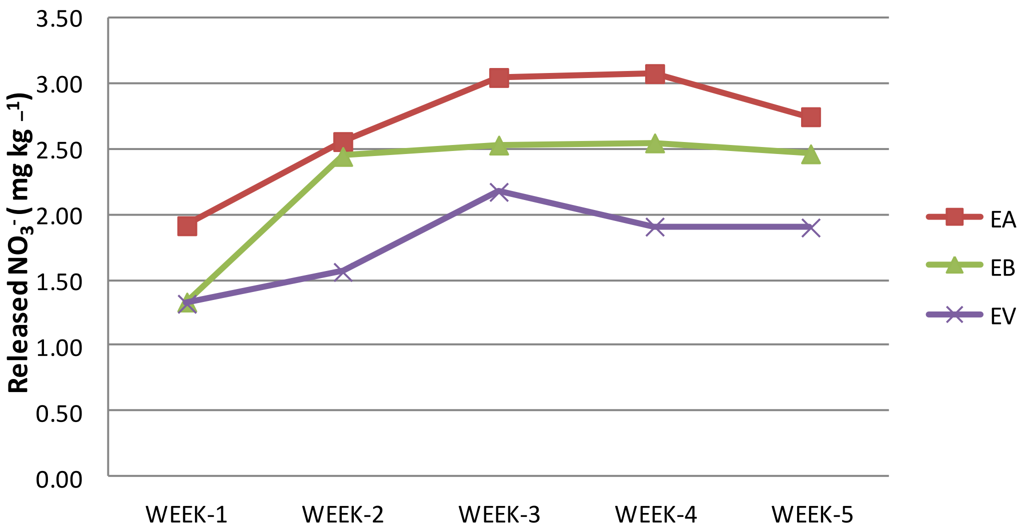

Figure 2. Release of NO_3^- in Cambisols during decomposition.

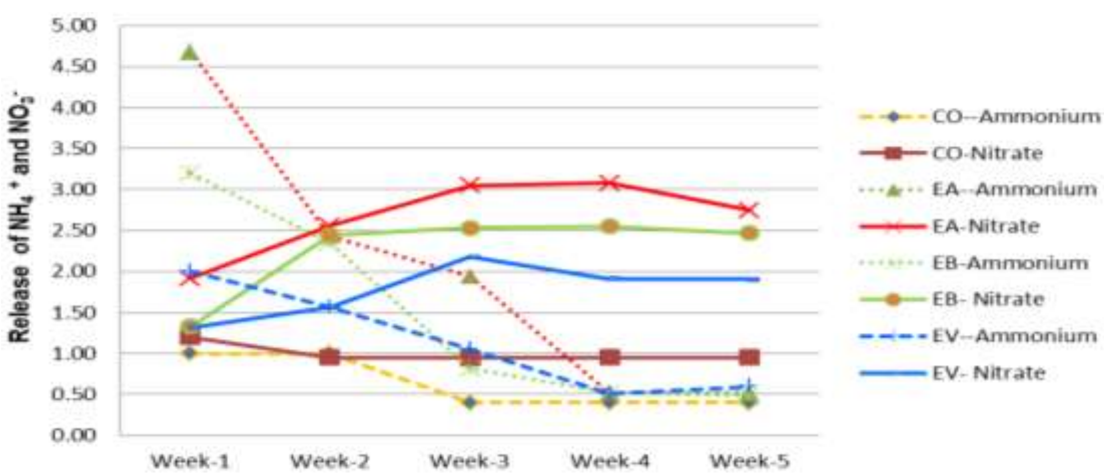

Figure 3. Release of NH_4^+ and NO_3^- in Cambisol.

The results of this study revealed that the nitrification significantly ($P < 0.05$) varied at every incubation week and within three of the ONS amendments. During the five weeks of incubation, the nitrification of the control was at the lower rate, compared to the ONS amended (Figure 3).

The decrease in amount of NO_3^- starting the fourth week and latter might be caused by leaching (because of its high solubility) and denitrification. Because of its negative charge, NO_3^- is not retained by the soil's cation exchange site and can be easily lost from the root zone by leaching and denitrification (Mengel and Kirkby, 1987). Aber et al. (1989) had also explained under conditions in which N inputs exceed biological demand, the production of nitrate, or nitrification, may increase with the eventual loss of nitrate from the system besides addition of organic nutrient sources that enhanced net nitrification remarkably due to its favorable chemical composition. Khalil et al. (2002) also reported similar results, indicating the inherent microbes potentially accelerating the process of denitrification. Also Haney et al. (2004) outlined that in some instances net nitrification was higher than net mineralization, indicating immobilization/fixation and other N loss phenomena. Furthermore, Fu et al. (1987), Vahdat et al. (2011) and Morse et al. (2015) observed that the application of organic residues produced more mineral N in the form of NO_3^- under neutral and slightly alkaline conditions.

Table 5. Interaction effect of EA, EB, EV and incubation period (weeks) on TN.

Week	CO	EA	EB	EV
1	0.10^{j}	0.29^{a}	0.23^{dc}	0.15^{f}
2	0.10^{j}	0.25^{b}	0.23^{c}	0.14^{gf}
3	0.12^{ih}	0.22^{dc}	0.21^{de}	0.13^{gh}
4	0.11^{ij}	0.22^{dc}	0.20^{e}	0.12^{ih}
5	0.10^{j}	0.21^{de}	0.20^{e}	0.12^{ih}
CV (%)	**5.13**			

Means in a column followed by the same letters are not significantly different.

Table 6. Interaction effect of EA, EB, EV and weeks on OC content.

Week	CO	EA	EB	EV
1	1.72^{j}	4.62^{a}	3.75^{c}	2.52^{f}
2	1.58^{k}	4.12^{b}	3.14^{d}	2.33^{g}
3	1.54^{lk}	2.58^{e}	1.92^{h}	1.47^{m}
4	1.50^{lm}	1.91^{h}	1.84^{i}	1.21^{n}
5	1.50^{lm}	1.84^{i}	1.50^{lm}	1.20^{n}
		CV (%)	1.11	

Means in a column followed by the same letters are not significantly different.

Table 7. Interaction effect EA, EB, EV and incubation period (weeks) on C:N.

Week	CO	EA	EB	EV
1	17.00^{ba}	15.67^{bc}	17.00^{ba}	17.00^{ba}
2	16.00^{bac}	16.67^{bac}	13.67^{e}	17.33^{a}
3	13.00^{ef}	12.00^{f}	9.33^{hg}	11.67^{f}
4	14.00^{ed}	8.67^{hg}	9.00^{hg}	10.00^{g}
5	15.33^{dc}	8.67^{hg}	7.67^{h}	10.00^{g}
CV (%)	6.2			

Means in a column followed by the same letters are not significantly different.

Changes in organic carbon, total nitrogen and C:N ratio of the ONS

Release of OC and TN

During the incubation experiment, the TN, and OC contents of the ONS were significantly different at each incubation week (Tables 5 to 7 and Figure 4). Moreover, a decreasing trend was observed during the mineralization processes.

There were significant differences in TN and OC content of each of the organic nutrient sources applied. In the study of mineralization of EA, EB, and EV, in cambisols a high and positive correlations ($r = 0.766$, $P \leq 0.0001$) was found between OC and TN, indicating that there was strong association of OC and TN in the mineralization processes.

The laboratory analysis showed that the EA leaves had the highest TN followed by EB and EV during the mineralization (Table 6). However, initially the OC content

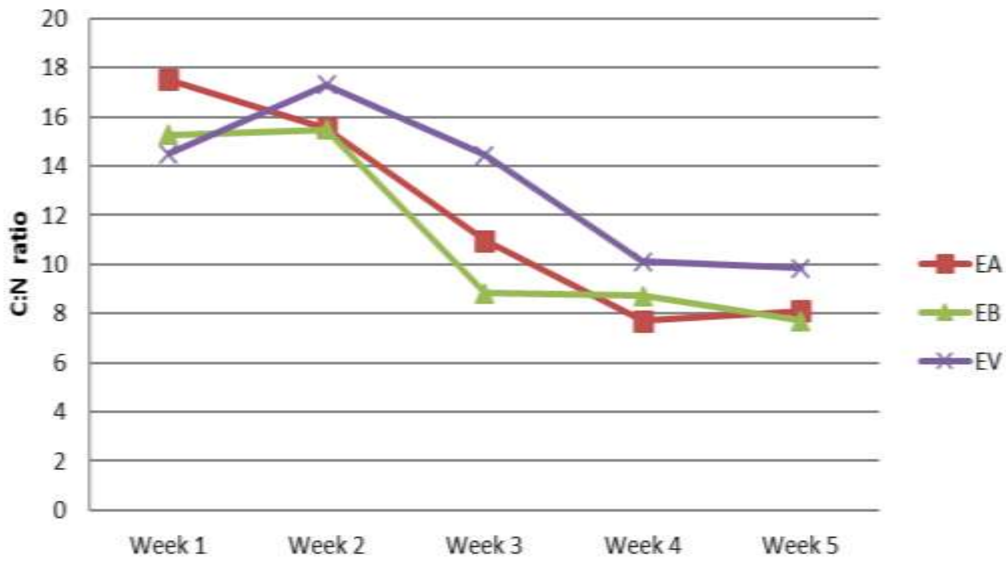

Figure 4. Decomposition of EA, EB and EV in Cambisol and the status of C:N ratio.

of the ONS was higher. In support of these results, the study conducted by Fu et al*.* (1987) showed that the mineralization process was influenced by N supplying capacity that depends mostly on the initial soil organic matter, the addition of organic residues, and the various soil environmental factors.

OC: TN of ONS

The mineralization of EA, EB and EV in Cambisol, revealed that their initial C:N ratio were affected by mineralization and nitrification process (Table 7 and Figure 4). The decomposition of EA, EB and EV had negative and high significant difference in terms of C/N ratio ($r= -0.7534$; $p \leq 0.0001$) and weeks of incorporation, indicating that as weeks of incorporation goes on C:N ratio was decreasing. The C:N ratio in the incubation experiment indicated that the highest ratio was obtained from EB and EV in the first week. Perez-Harguindeguy et al. (2000) found that the C:N ratio was also found to be a good predictor of decomposition rate, due largely to the fact that higher C:N values are often associated with compounds showing higher C enrichment, particularly lignin. Similarly, high OC content may be due to the initial high C:N ratio and the difference in TN content of each ONS. In line with these, Stemmer et al. (1999) reported that when stabilized organic products with adequate C:N ratio (< 20) are added to the soil, the mineralization process is enhanced, while products with high C:N ratio promote immobilization. Consequently, the low C:N ratio may have assisted fast mineralization of the three ONS in Cambisols.

Conclusion

EB and EV species are categorized as the fast decomposing organic materials with medium to highest TN content. Incorporating ONS to Cambisols showed an increase in NH_4^+, NO_3^-, TN and OC content of the soil as compared to their respective controls. Based on the pattern of release of NH_4^+, NO_3^-, TN and OC content, the species showed the order: EA >EB > EV. Reduction in concentration occurred at the fourth week, which showed that the NH_4^+ was aerobically converted to NO_3^- providing empirical evidence to support the theory that decomposition of EA, EB and EV are governed by first release of NH_4^+. In the mineralization processes the release of NO_3^- followed the reverse trend of NH_4^+release.

This study has shown that EA, EB and EV had similar N-mineralization pattern, releasing most of their NH_4^+ content within two weeks of incorporation into the soil. The fact that these materials are high quality, it is expected that they decompose faster and release N.

Conflict of Interests

The authors have not declared any conflict of interests.

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