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Initial Litter Chemical Indices as Selection Criteria of Organic Nutrient Resources for Enhancement of Soil Fertility for Smallholder Farmers in Southern Ethiopia

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Abstract: Nutrient release from applied organic nutrient source (ONS) depends on temperature, soil moisture, soil properties, their chemical composition and microbial activity. In order to apply ONS to fulfill the nutrient requirements of plants, knowledge of quality and quantity of chemical constituents of the ONS has paramount importance. *Erythrina abyssinica* (EA), *Erythrina brucei* (EB) and *Ensete ventricosum* (EV), the first two being nitrogen-fixing indigenous multipurpose agroforestry trees in Ethiopia, were randomly collected from Southern Ethiopia. The average total nitrogen (TN) contents of EA, EB and EV were 4.05%, 3.35% and 2.56%, respectively. Similarly, the mean total soluble polyphenolics contents were 0.052%, 0.023% and 0.19%, and the mean lignin contents were 9.7%, 12.6% and 6.5%, respectively. In general, these ONS had medium to high TN content. Thus, the ONS can be selected based on their quality, quantity and ratio of their chemical constituents as alternative or supportive organic sources. A "decision tree" is best fitted for selection of these ONS.

Key words: Lignin, polyphenolics, TN, total organic carbon (TOC).

1. Introduction

Incorporation of organic nutrient sources (ONS) into soil assists in sustaining soil organic matter content, enhances biological activity, lowers bulk density, enhances nutrient availability, improves water infiltration, decreases evaporation and increases water-holding capacity of soils [1, 2]. To improve soil productivity, incorporation of local organic residues has been gaining worldwide support [3]. Farmers are using some plant species with high nitrogen-fixing capacity as ONS in different localities of the Southern Nations, Nationalities and Peoples' Region (SNNPR). *Erythrina abyssinica* (EA) and *Erythrina brucei* (EB) are some of indigenous nitrogen-fixing trees and *Ensete ventricosum* (EV) is multipurpose agroforestry plants widely grown in the Southern and Southwestern part of Ethiopia.

Erythrina spp. occurs over a wide range of natural habitats, including open forest, dry brush and scrub, riverbanks and swamps. EA is leguminous tree species native to East Africa and Eastern Democratic Republic of Congo, especially to Northern and Western Ethiopia. EB is also a leguminous tree endemic to Ethiopia [4] and nitrogen-fixing tree [5] adapted to growing in areas with altitude ranging from 1,400 m to 2,600 m above sea level.

EV although is a wild relative of *Ensete* and grows across many regions of Africa; it seems to be domesticated only in Ethiopia [6].

Many researchers have drawn several different conclusions regarding the chemical characterization that determines the release of nutrients from the plant materials under their investigations. Numerous researchers have suggested that the major litter quality variables of controlling decomposition rates and the basis for selection of ONS are generally predicted by the initial concentrations of N, P, polyphenol, lignin,

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C:N, lignin:N and polyphenol:N ratio [7-11]. However, another study [12] indicated that N release patterns are more dependent on polyphenol content.

There is an increasing tendency for the exploitation of plant chemical composition to use as organic fertilizers. In this regard, to meet the nutrient demand of the crops, especially planted by the resource-poor farmers, the use of ONS would be an inevitable practice, and studying the chemical indices of the EA, EB and EV will provide useful information on the selection of appropriate type of ONS to be used for soil fertility enhancement for smallholder farmers.

2. Materials and Methods

2.1 Description of the Sampling Sites

The SNNPR is located in the Southern part of the Ethiopia and on the borders of the South of Kenya, the Southwest of the Sudan republic, the Northwest of Gambela region and the North and East of Oromiya region. The region lies between 4°27′ to 8°30′ North and 34°21′ to 39°1′ East. It has an area of about 110,931.9 km^2, which ranks 4th in size in the country. The total area of forestland in the region is about 54,142 km^2, of which 42% is woodland, 31% is bush land, 13% is broad leaf and mixed forest, 9% is shrub land and the remaining 5% is plantation forest [13].

The study was conducted at the College of Agriculture of Hawassa University during March to June 2012 at Hawassa, the capital of SNNPR. Hawassa is located in the Rift Valley zone of Ethiopia, at the Eastern shore of Lake Hawassa and 275 km South of Addis Ababa. Geographically, it is situated at 07°03′ North and 38°29′ East with an average altitude of 1,750 m above sea level.

2.2 Plant Sampling and Sample Preparation

Plant sampling was done according to the procedure described by Ref. [14], in which representative leaves (old and new) and twigs were sampled from randomly selected EA, EB and EV plants. The ONS were collected from SNNPR. The plant samples were washed using 0.1% to 0.3% detergent solution for few seconds, washed thoroughly with tap water and then rinsed with distilled water.

2.3 Determination of Ash Free Dry Weight and Total Organic Carbon (TOC)

The ONS samples were dried at 40 °C for 72 h and then cooled in desiccators for 45 min. One gram ONS sample was weighed and transferred to a crucible, followed by pre-calcinations and then combustion in a furnace at 550 °C for 6 h. The samples were weighed after cooling the furnace. The ash free dry weight was calculated as Eq. (1):

$$\text{Ash free dry weight} = [(A - B) \times 100]/(B - C) \quad (1)$$

where, A = weight of air dry ONS material + crucible weight; B = weight of calcinated ONS material + crucible weight; C = weight of empty crucible. Then TOC was assumed to be 50% of its ash free dry weight and expressed as Eq. (2) [15]:

$$\text{TOC} = \text{ash free dry weight}/2 \quad (2)$$

2.4 Determination of Polyphenolics Content

Total extractable polyphenol were analyzed by the Folin-Denis method adapted from Refs. [16, 17].

2.5 Determination of Lignin and Cellulose via Acid Detergent Fiber (ADF)

In the study, Klasson method in Ref. [18] was selected for the analysis of lignin and cellulose via ADF. It is based on the removal of cellulose by hydrolysis with 72% H_2SO_4, fats and lipids with alcohol and benzene, soluble carbohydrates with water, starch with dilute acid and protein with enzyme. The chosen method is based on ADF method [19] and is crude measurement of resistant organic materials.

ADF is prepared from ONS material by boiling with sulphuric acid solution of cetyltrimethyl ammonium bromide (CTAB) under controlled condition. The CTAB dissolves nearly all nitrogenous constituents, and the acid hydrolyses the starch to residue containing lignin, cellulose and ash [20].

Cellulose is destroyed by 72% H_2SO_4; lignin is then determined by weight-loss upon ashing.

2.6 Statistical Analysis

The data obtained from the ONS analysis were subjected to analysis of variance (ANOVA) using statistical analysis software version 9.3 [21]. The least significant difference (LSD) was used to separate the means at $P \leq 0.05$.

3. Results and Discussion

3.1 Chemical Characterization of EA, EB and EV as Indices for Their Litter Quality

TOC, total nitrogen (TN), total potassium (TK), total phosphorus (TP), total polyphenol (TPP) and total lignin contents of the ONS were determined to study the chemical factors that control the decomposition of organic sources [10, 22].

3.2 TN Content of EA, EB and EV

The TN content of EA ranged from 3.16% to 5.16% with an average of 4.05%. In this study, the average TN content of EA was found to be 4.05%, and can be categorized under the highest nitrogen-fixing plants, as outlined by Jones [23] who described that nitrogen constitutes 1.5%-6.0% of the dry weight of many crops.

The TN content of EB ranged from 3.93% (the highest value) to 2.77% (the lowest value). At some places, if the TN content exceeded the highest rating level by Ref. [24], it can be rated as medium in terms of nitrogen fixation. Whereas, TN content of EV (1.16%-3.16%) with average 2.55% can be rated as low nitrogen containing plant, as compared to the common organic sources, such as pigeonpea fresh leaves (3.24%), pigeonpea litter (1.63%) and *Sesbania* (3.44%) [25].

According to Chapman [24], plant leaves have a range of TN content from about 1.5% to 3.5%, depending on the crop and age of the leaf, etc.; whereas EV (2.68%) can be grouped among the medium nitrogen-containing ONS, as compared to the above mentioned studies.

EA > EB > EV is the order of TN content. The variation in TN content of EB and EV can be due to cumulative contribution of micro agro-climatic factors—soil fertility, temperature and microorganism.

3.3 TP Content

There was significant difference in TP content among EB, EV and EA ($P \leq 0.05$). The results revealed that the TP content in EA was higher and significantly different from EB and EV (Table 1); this difference may be due to the phosphorus extracting ability of EA. Since EA is growing at high altitude and in soils with very strong acidity and high phosphorus fixation capacity; it can extract phosphorus more efficiently than the EB and EV. The TP contents of these three organic nutrient sources are little higher than that reported by Schachtman et al. [26], who stated that phosphorus constituted about 0.2% of ONS dry weight. Studies conducted by Gachene et al. [27] revealed that *Lablab purpureus* contained 0.18% phosphorus and *Canavalia ensiformis* contained 0.16%. Aerts and De Caluwe [7] showed that in addition to TN and C:N, other parameters such as

Table 1 Mean of TN, TP and TK contents of EA, EB and EV.

ONS	TN (%)	TK (%)	TP (%)	TN:TP
EA	4.05^a (3.16-5.16)	2.02^c (1.94-2.08)	0.39^a (0.36-0.43)	10.77
EB	3.36^a (2.70-3.93)	2.61^b (2.54 - 2.68)	0.31^b (0.30-0.32)	11.29
EV	2.55^b (1.16-3.16)	4.2^a (4.04-4.5)	0.26^b (0.23-0.28)	9.62
LSD (0.05)	0.76	0.36	0.05	
CV (%)	13.01	6.32	8.01	

CV: coefficients of variation. Values in brackets mean range. Means in a column followed by the same superscript letters are not significantly different at $P \leq 0.05$.

Table 2 Chemical characterization of EA, EB and EV.

ONS	TPP	ADF	Lignin	Cellulose	TOC	TN	Cellulose:N	ADF:N	Lignin:N	TPP:N	(Lignin + TPP):N
	(%)										
EA	2.04[a]	30.57[b]	9.70[b]	1.10[b]	43.36[a]	4.15[a]	10.44[c]	12.07[a]	2.34[c]	0.49[a]	2.75[b]
EB	1.05[b]	34.37[a]	12.63[a]	1.80[a]	41.09[b]	3.35[b]	12.26[b]	10.25[b]	3.77[a]	1.24[a]	4.08[a]
EV	0.08[c]	30.97[b]	6.53[c]	0.52[c]	41.14[b]	2.55[c]	16.13[a]	7.34[c]	2.56[b]	0.03[a]	2.59[b]
CV (%)	0.83	1.83	1.77	12.53	0.21	1.50	2.61	2.00	2.27	15.7	4.21
LSD (0.05)	0.017	1.17	0.34	0.29	0.18	0.10	0.67	0.36	0.13	1.85	0.26

CV: coefficients of variation. Means in a column followed by the same superscript letters are not significantly different at $P \leq 0.05$.

N:P seemed to be good predictors of residue decomposition rate. Berg and Laskowski [28] showed that there was a general tendency for forest floor humus layers to have N:P ratio near 15. Initial patterns of N and P accumulation and release may be best predicted by the N:P ratio of the litter.

Thus, litters with initial N:P ratio > 15 are more likely to release N and retain P, while those with N:P < 15 are likely to retain N and release P. Since all the three ONS had N:P < 15, they are likely to retain N and release P.

EB > EA > EV was the order of TN:TP ratio. Some other studies, like Refs. [29, 30], had suggested that initial concentration of N or P in litter may also influence rates of late-stage decay (Table 1).

3.4 TK Content

The ONS collected from SNNPR had high to medium TN content, and hence can provide good amounts of K to the soil as well. While EA had the highest TN and the lowest TK contents, and the reverse was true for EV (Table 1). All the three ONS were significantly different with respect to TK content ($P \leq 0.05$). The highest value of K in EV could be due to the fact that it continuously received organic matter, particularly manure [31]. The *Ensete* garden is the dump site of most of the other organic residues, such as household wastes, leftover feed, organic sweepings around the house and other recycled organic materials [31].

The study conducted by Westerman et al. [32] showed that fresh and scraped beef manure had K contents of 2.5% and 2.0%, respectively. Thus, EB and EV had better K content than beef manure, and far better than *Sesbania* 11.7 mg/g, pigeonpea litter 9.8 mg/g, and others [25]. EV > EB > EA was the order of TK content in the ONS.

3.5 TOC Content and C:N ratio of EA, EB and EV

Leaves of EA, EB and EV had N concentrations > 2.5%, C:N ratio < 17 and (lignin + polyphenol):N ratio < 5 (Table 2). The study [10] suggested that initial N concentration or C:N ratio were important factors that influenced the degradability of organic residues. In line with this, the study conducted by Probert et al. [33] indicted that for ONS with C:N < 20, net mineralization occurs from the outset. Nevertheless, wherever C:N > 20, initially immobilization of mineral N takes place, followed by re-mineralization, and thus leads to increased mineral N in the system. Also Refs. [9, 11, 33] concluded that initial N concentration or C:N ratio of residues was the main factor to control decomposition and nutrient release.

3.6 TPP Content

In this study, the highest TPP content (2.04%) was found in EA and the lowest (0.08%) in EV, while EB (1.05%) was intermediate (Table 2). Thus, TPP contents were in the order: EA > EB > EV. The study conducted by Anis et al. [34] indicated that there were differences in the percentage of N mineralized, and its rate can be determined by the litter quality of the crop residues, especially N, lignin and polyphenol content. Some of the many factors that influence the activity of decomposers are polyphenols or tannins as described by Ref. [12]. Srisuda et al. [35] found the TPP content of 1.84% in peanut leaves and 2.31% in pigeonpea leaves.

Likewise, Grubesic et al. [36] observed that leaves of *Pouteria altissima* contained 4.55% TPP. Moreover, the TPP contents in different parts of *Plantago holosteum* were: leaves 10.15%, stems 4.13% and flowers 3.91%. In the present study, EA, EB and EV had the lower TPP content than those reported by Srisuda et al. [35] and Grubesic et al. [36]. In line with this, Palm and Sanchez [37] had also reported that both the decomposition rate and the N-release patterns of three tropical legumes (*Inga edulis*, *Cajanus cajan* and *Erythrina* spp.) were related to the amount of polyphenol compounds, such as lignin in their leaves.

3.7 Total Lignin Contents

EB leaves contained the highest total lignin content 12.63%, whereas EV had the lowest 6.53%. In general, increasing lignin concentration reduces the residue decomposition rate [30]. Accordingly, EV will be the first to decompose, followed by EA and EB, respectively (Table 2). In contrast to the above rating, Refs. [38, 39] showed that high lignin in pigeonpea or high polyphenol in hairy indigo was expected to influence the rates of decomposition, but they showed very poor correlation to the rate constants of the TPP and total lignin contents. In Refs. [10, 40], it was revealed that the decomposition rate of ONS is related to lignin:N ratio than the lignin content only, and accordingly EA decomposes first, followed by EV and EB. However, Palm and Sanchez [12] indicated that other factors particularly TPP or tannis were the primary factors to influence the decomposition rate; accordingly, in the order of fast decomposition, EV will be first to decompose, followed by EB and then EA.

3.8 Lignin:N and Polyphenol:N Ratios

Some researchers concluded that it is the different ratios (such as lignin:N, TPP:N and others parameters as indicated in Table 2) that regulate the decomposition of ONS. Other studies carried out by Handayanto et al. [41] noted that the initial lignin:N ratio and the (lignin + polyphenol):N ratio were strongly correlated with the decomposition rates or N accumulation; while in other studies, the (lignin + polyphenol):N ratio was a good predictor when dealing with complex materials. Also Refs. [41, 42] suggested that the N concentration or the ADF:N ratio were more suitable predictors. Following their findings, the order of fast decomposition will be EV > EB > EA in the present case. In contradiction to these, Constantinides and Fownes [22] noted that the decomposition rates and N release in leguminous plant residues with high N content are usually high. Based on this criterion, the decomposition order will be EA > EB > EV.

Leaf residues have generally been described as high-quality litter materials in terms of high N and low lignin contents [37, 43]. A high ADF and (lignin + polyphenol):N ratio might have caused a slower decomposition of leaf litters (Table 2). This could be similar to Handayanto et al. [41], who stated that the lower net decomposition was probably due to the fact that polyphenols were not very active in binding proteins or inhibiting enzyme activities, showing only a minor influence of polyphenols.

Similarly, it can be drawn a conclusion on the ONS ability to resist decomposition based on the study conducted by tropical soil biology and fertility (TSBF) program (Fig. 1). To decide decomposition rate of the ONS based on the TSBF rating, for example their TN, lignin and TPP content, thus EA, EB and EV had > 2.5% TN, < 15% lignin and < 4% TPP. Moreover, Table 2 indicated the results of litter quality parameters and the ratios of EA, EB and EV lie in the same group.

4. Conclusions

The chemical characterization of EA, EB and EV revealed that their TN contents were > 2.5%, lignin content < 15% and polyphenol content < 5%. Based

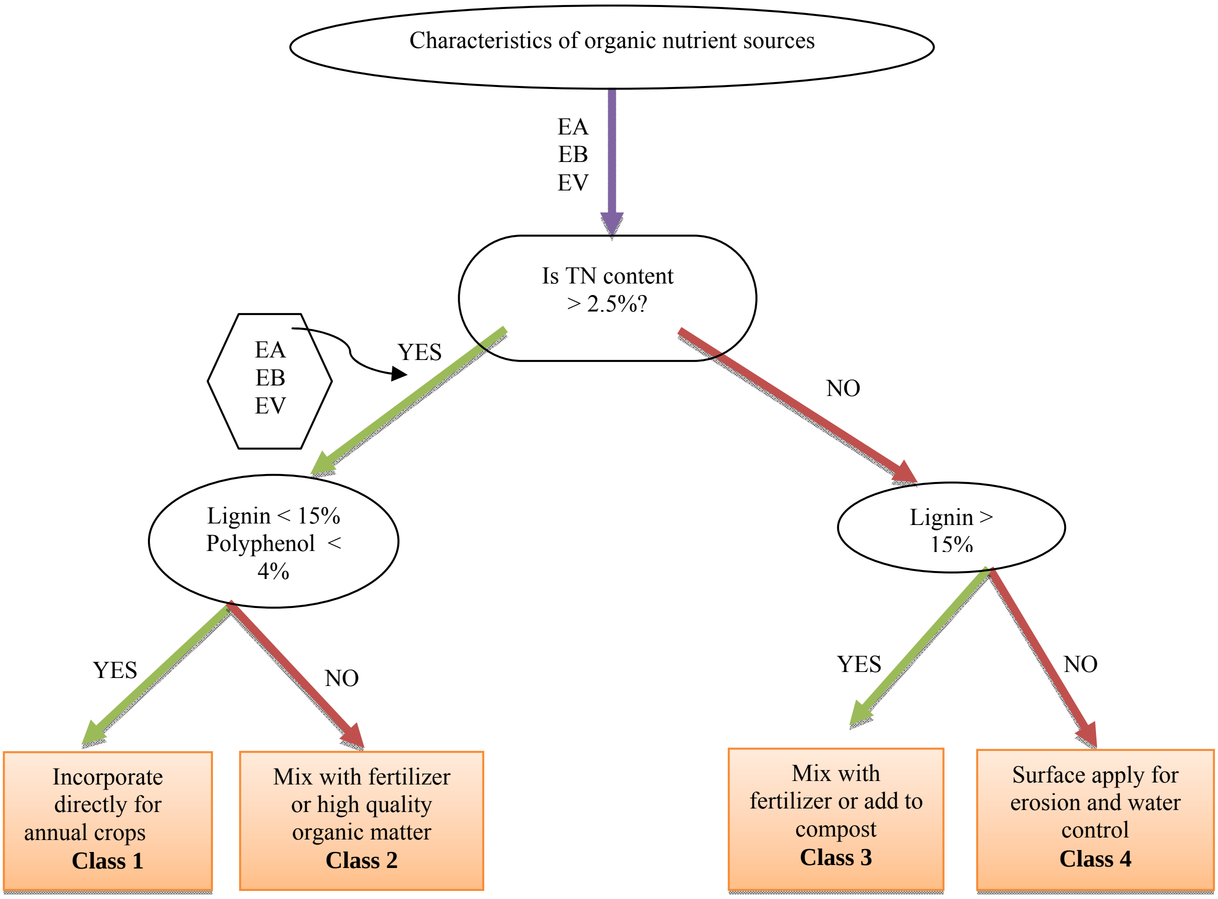

Fig. 1 Decision tree to assist management of organic sources in agriculture based on chemical characteristics.
Source was from Ref. [44].

on these quality indices, they are rated as high quality (Class 1) ONS. However, Ensete was found to contain relatively low amount of P but high amount of K as against to *Erythrina* spp.. The EV was hypothesized to be of the lower quality than the agroforestry EA and EB because of its non-leguminous nature. The high quality of ONS could be accounted for their highest TN content and low ADF concentrations. The results of the present study also indicated that three of the ONS differed with respect to chemical constituents (lignin, TPP, TN, TOC) which regulate the litter quality. Among the three ONS, EB had the higher lignin (12.63%) and ADF (34.37%) content than EA and EV; while EV had the higher TK content (4.2%) than EB and EA; EA had the highest TN content (4.05%) than EB or EV. These plant species also had the high P contents comparable to those of *Tithonia* which is known for its high organic P content; still both of the *Erythrina* spp. have fairly high amount of K in their leaves. This implies that these ONS can be a good source of P and K in addition to N for smallholder farmers. Thus, from the decision tree (Fig. 1) and other parameters discussed above, all three of ONS can be categorized in fast decomposing ONS (Class 1) and may be incorporated directly for annual crops.

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