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Litter decomposition and release of nutrients form *Eucalyptus camaldulensis* leaf on Eucalypt plantation soils

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ABSTRACT

The decomposition and nutrient release from the leaf litter of *Eucalyptus camaldulensis* in six different plots under Eucalypt plantation soils were investigated. Six soil samples as well as leaf litter from each plot were collected from the plantation. Using standard methods, the soil samples as well as the leaf litter samples were analyzed for chemical properties (pH, Organic carbon, nitrogen, phosphorus, potassium, calcium and magnesium). Microbiological characteristics (Total viable bacteria and fungi, and Carbon (IV) oxide evolution) of the decaying leaf litter samples were also determined. All analyses were done at day 1, 30 and 60 of the decomposition period. Litterbag study was employed; each litterbag contained a soil and its corresponding leaf litter obtained from the particular plot were designated as E1 – E6. The decomposition rates of the litter in E1, E2, E3, E4, E5 and E6 were found to be 0.00393, 0.00331, 0.00479, 0.00571, 0.00548 and 0.00271 respectively. The results showed that there was a general decrease in nutrient status of the litter and an increase in soil nutrient during the decomposition period. Pearson's correlation matrix revealed that there was a positive correlation in the release of nutrient from the leaf litters and their return to the soil at day 1, 30 and 60 in almost all the samples. It was also found that the total viable bacteria and fungi were statistically associated. These were attributed to their different soil microbiological and chemical properties. It is concluded from this study that decomposition and release of nutrient from *E. camaldulensis* leaf litters in different plots under Eucalypt plantation soils are differed according to plot condition.

***Keywords*:** *E. camaldulensis*; Leaf litter decomposition; Physicochemical and microbiological properties; Eucalypt plantation; Nutrient release

1. INTRODUCTION

Litter decomposition is a fundamental biogeochemical process influencing rates of carbon and nutrient cycling in forest ecosystems (Perry *et al.,* 2008). Leaf tissue can account for 70% or more of above-ground litter fall in forests, with the remainder composed of stems, small twigs and reproductive structures (Robertson and Paul, 1999). The interactive and sequential processes of litter fall, its decomposition and subsequent mineralization are essential in sustaining a dynamic forestry/agriculture ecosystem. This is important because the availability of nutrients and their plant uptake depends upon the reabsorption and retranslocation of the nutrients before leaf fall and subsequently on decomposition and mineralization of the organic matter. Litter-fall is the primary mechanism for transfer of plant detritus from above-ground parts of forest trees to the soil surface. Decomposition of this litter provides the main source of energy and nutrients for soil and litter organisms, and is a major pathway for the recycling of nutrients to the plant community (Charley and Richards, 1983). The litter on the forest floor acts as input–output system of nutrient and the rates at which forest litter falls and subsequently, decomposes contribute to the regulation of nutrient cycling and primary productivity, and to the maintenance of soil fertility in forest ecosystems (Onyekwelu, 2006). According to Swift *et al.* (1979), the rates and pathways of litter decomposition are determined by the qualitative and quantitative composition of the decomposer community, their physical environment and the quality of the resources that animals and microorganisms are utilizing. The substrate quality includes not only the concentration and availability of nutrients, but also modifiers such as tannins which affect the activity of heterotrophs.

Decomposition of organic matter has received growing attention in recent years because of its role in nutrient cycling and in supporting saprophagic component of the forest ecosystem. The decay of organic matter and its return to the soil via litter fall is an important source of inorganic ions for vegetation uptake. Nutrients are released from decaying organic matter by physical (leaching) and biological (microbial decay) processes (Baker and Attiwill, 1985). The sequence from fresh litter to stable soil organic matter has been defined as a decay continuum (Melillo *et al*., 1989). Release-immobilization pattern of nutrients proceed through time in different ways according to the mobility, concentration and biotic role of nutrients, the activity of organisms and the physical environment. According to Rigbelis and Nahas (2004), the most important soil nutrient supply to the forest soil environment is the one derived from litter decomposition by actions of organism under conditions of high air temperature and soil moisture content. Soil being one of the most complex and heterogeneous environments, contains significant microbial diversity (Tiedje *et al*., 1999).

Eucalyptus spp. are trees that grows extremely fast in warm and humid climates. Because of their great environmental adaptability, excellent form and rapid growth, they are the most widely planted industrial exotic plants (Jairus *et al*., 2011). Exotic plantation species have the characteristics of fast growth rate and thereby take up nutrient at a fast rate from the soil, leading to a reduced soil fertility. There is need therefore for a rapid decomposition of litter from these exotics to balance rapid nutrient depletion from the soil and avert soil

degradation. Soil microbial biomass is suitable and commonly used as potential indicator of soil organic matter levels (Sicardi *et al*., 2004). Organic stocks and litter fall rates, organic matter disappearance, nature of soil together with distribution of microbes influence decomposition rates. However, the above-ground net productivity and nutrient concentration in leaves among exotic plantation species differ markedly according to site conditions and nature of soil (Cozzo, 1976; Marcó, 1988; Goya *et al.*, 1997a, b). The C:N, C:P and N:P ratios, as well as lignin:N, have been used as quality indexes of decomposing organic matter in different ecosystems (Brinson, 1977; Vogt *et al*., 1986; Baker III *et al.*, 2001). Ratios also indicate the relative abundance of nutrients considered and some thresholds have been established where decomposition readily occurs (Alexander, 1977). Physicochemical properties of soils are important controlling decomposition processes and dry matter quality (Anderson and Flanagan, 1989).

The hypotheses stated were: (1) there is no difference in the decomposition rate among leaf litters in different soils under *E. camaldulensis* plantation (2) The release-immobilization pattern of each nutrient through leaf litter and its return to the soil is different due to different plot conditions under *E. camaldulensis* plantation (3) Soil microbiological and physicochemical properties in relation to decomposition of leaf litter are different in different plots under *E. camaldulensis* plantation.

2. RESULT/ EXPERIMENTAL

2. 1. Study site

This study was conducted at Afaka exotic tree plantation near Nigerian Defence Academy, Kaduna, Nigeria (NDA). It is located at latitude 10° 36' 21.28" N and longitude 7° 18' 57.17" E, Kaduna State, Nigeria. The estimate terrain elevation above sea level is 629 metres. This area experiences tropical continental (savanna) type of climate which has two seasons in a year. The dry season which starts from mid to late October ends up in mid to late April. The wet season often last from April to October. Each season lasts for about six months. A mean annual rainfall of about 1200 mm is usually recorded in the rainy season and the mean annual temperature is about 24.5 °C (Nwaedozie *et al.*, 2013).

2. 2. Decomposition assay

Leaf litter and soil samples were collected from six different plots in *Eucalyptus* compartment of Afaka exotic plantation. The leaf was air-dried to a constant moisture content before the beginning of the decomposition assay employing the mesh-bag method (Bocock *et al.*, 1960). Six sets of litterbags were used for decomposition assay. The litter decomposition studies was carried out using the mesh bag technique described by Mary and Sankaran (1991) and Osono and Takeda. (2001). 10 g of air-dried leaf litter and soil obtained from different plots were transferred separately in nylon mesh bags- (mesh size 2 mm) and the openings closed firmly by stitching. Control sets contained soils without litter bags. Each soil-containing litters was watered with 20 ml of deionized water periodically to maintain 60-70% water holding capacity. Samples of each were weighed after drying in an oven at 105 °C for 24 hours to determine the constant weight. Average mass loss of leaf litter from litterbags was calculated by subtracting the final mass of dry matter after oven drying from original (initial) mass of dry matter (Vesilind *et al*., 2002).

Residual dry mass of litter was determined after 1, 30 and 60 days, then percentages of total litter undecomposed was calculated at each time and the rate of decomposition constant, *k* (day^{-1}) of leaf litter was estimated from these data by negative exponential decomposition model proposed by Olson (1963).

2. 3. Determination of Microbial Activity (CO_2 Evolution)

Basal respiration was determined by measuring the rate of CO_2 evolution from the decomposing litter following the method described by Mary and Sankaran (1991), Qingkui *et al* (2008) and Cortez *et al* (2014). Soil samples (100 g) were placed in 500 ml glass containers closed with rubber stoppers, moistened at 60% of the maximum water holding capacity and incubated for 3 days at 25 °C. Glass vials holding 10 ml of 0.5 M NaOH to trap the evolved CO_2 were placed in the above containers. On day 3 after incubation, the glass vial was removed and the CO_2 trapped in NaOH was determined titrimetrically. The residual alkali was titrated against 0.1 M HCl using phenolphthalein as indicator and CO_2 evolution from litter was then calculated. A set of 500 ml glass containers containing litter-free soil served as the control. The difference between the values for soil with the litter and litter-free soil gave the CO_2 evolution from the enclosed litter. The amount of CO_2 evolved was converted into µg CO_2 g^{-1} oven dry litter day^{-1}.

2. 4. Microbiological and physicochemical analysis of soil and decaying leaf litter

Chemical analysis of leaf litter and soils was carried out at National Geosciences Research Laboratory (NGRL), Kaduna, Nigeria. Organic carbon was determined by Walkley and Black method (Walkley and Black, 1934). Available nitrogen was estimated by Kjeldhal method (Subbiah and Asija, 1956).

The content of P, K, Ca and Mg was analyzed in a solution after samples digestion in a mixture of K_2SO_4 + $CuSO_4$ + $FeSO_4$ in the ratio of 10: 0.5: 1 (Henway and Heidal, 1952; Black, 1965; Olsen *et al*., 1954). Soil pH was determined in a 1:2.5 (w/v) soil/water extract, with a glass electrode pH meter in soil solution of 0.01 $mol \cdot L^{-1}$ Calcium chloride (Rigobelo and Nahas, 2004). Microbial assessment of the samples was limited to fungi and bacteria. The standard procedures for determining the total number of microbes were adopted for bacteria and fungi culturing (Alexander, 1982). One gram of the decomposing litter was suspended in 10 ml of sterilized distilled water and serial dilutions of the suspension were prepared by further dilutions. One ml of the required dilution (10^{-5}) was plated in triplicate on nutrient agar amended with nystatin (300 µg/ml) to suppress the growth of fungi and potato dextrose agar amended with streptomycin to inhibit the growth of bacteria using pour plate methods. The nutrient agar plates was incubated at 37 °C for 24-48 hours while the potato dextrose agar plates was incubated at 28±2 °C for 72 hours. The number of viable microorganisms in the sample was calculated from the number of colonies formed and the volume of inoculums and the dilution factor expressed in colony forming unit.

2. 5. Data and Statistical analysis

Microbiological and physicochemical properties of soils and decaying leaf litter were carried out at day 1, 30 and 60 of the decomposition study. The loss in mass of the litter for each period was determined from the mass (M_1) of the remaining litter and Initial mass values (M_0) using the formula:

Table 1. Percentage mass loss, mass remaining and decomposition rate of *E. camaldulensis* leaf litter samples. The decay constant (*k*) was calculated after 60 days of decomposition.

	Decomposition	Mass Loss	Mass Remaining	Decay constant	Time required for Decomposition (Day)	
Sample	Time (Days)	(% ML)	(% MR)	*k* (day^{-1})	$t_{50\%}$ (Half-life)	$t_{95\%}$
E1	1	0	100	0.00393	176	763
	30	9	91			
	60	21	79			
E2	1	0	100	0.00331	209	906
	30	15	85			
	60	18	82			
E3	1	0	100	0.00479	145	626
	30	16	84			
	60	25	75			
E4	1	0	100	0.00571	121	525
	30	12	88			
	60	29	71			
E5	1	0	100	0.00548	126	547
	30	25	75			
	60	28	72			
E6	1	0	100	0.00271	256	1107
	30	11	89			
	60	15	85			

$$\% \text{ ML} = \left(\frac{Mo - M1}{Mo}\right) \times 100$$

The following exponential decay model was used to estimate the decomposition rate of litter. Decomposition constant (*k*) of leaf litter was estimated using the decay model (Olson, 1963).

$$\ln\left(\frac{Mo}{M1}\right) = kt$$

where 'M_0' is the initial mass of litter, 'M_1' is the mass of litter remaining after time t, 'In' is natural logarithm, 't' is the time (day) and *k* is the decomposition rate (day^{-1}). As proposed by Olson (1963), the time required for 50% and 95% mass loss was calculated as $t_{50\%} = 0.693/k$ and $t_{95\%} = 3/k$. respectively. Correlation analysis was carried out to determine the release-immobilization pattern of each nutrient through leaf litter and its return to the soil at day 1, 30 and 60. Correlation matrix was used to show the relationship of the soil samples (E1 – E6) in terms of microbiological and physicochemical properties at day 1, 30 and 60. Chi-square test was used to determine the significant association between total viable bacteria and fungi during decomposition.

2. 6. Decay rate

Table 1 reveals that the mass loss of leaf litter ranged from 15% (E6) to 29% (E4) after the period of decomposition study. There was a decline in the percentage mass of leaf litter remaining (Figure 2). The decomposition rates (day^{-1}) calculated according to decay model of Olson (1963) were 0.00393, 0.00331, 0.00479, 0.00571, 0.00548 and 0.00271 for the leaf litters of E1, E2, E3, E4, E5 and E6 respectively (Figure 1). However, the decomposition rate was highest in E4 requiring 525 days for 95% of it to decay (Table 1).

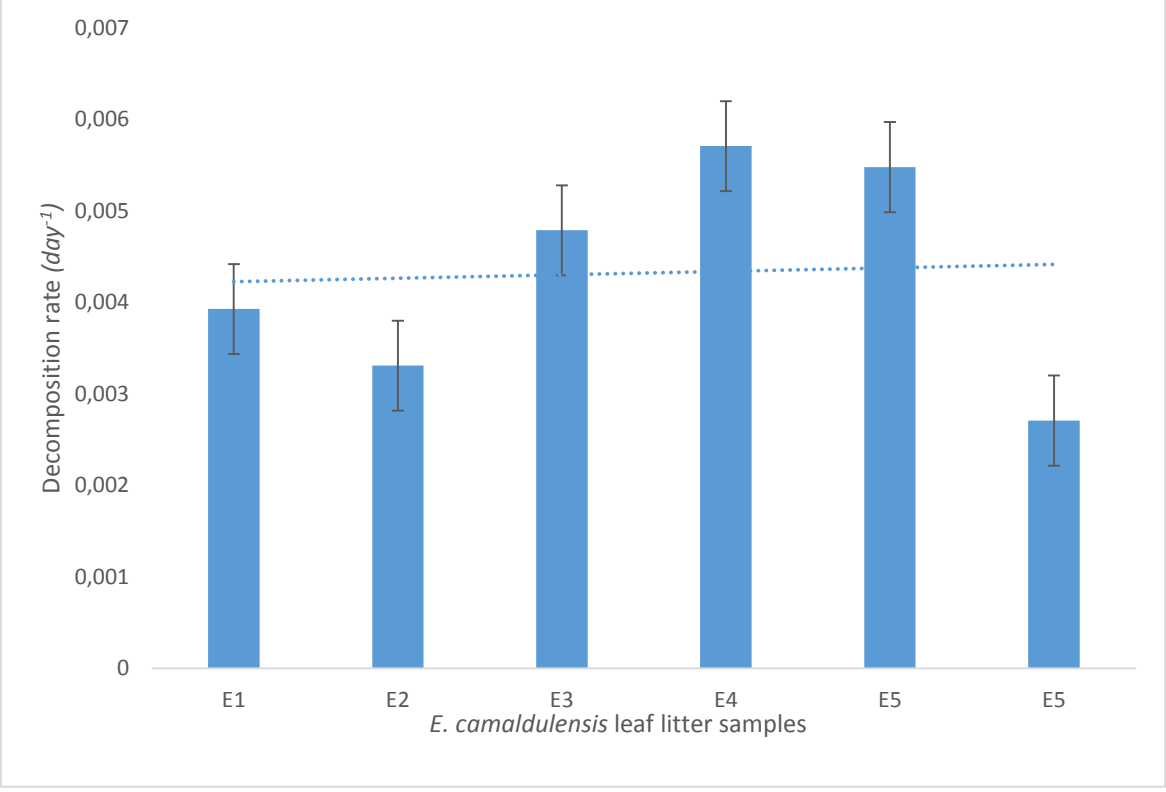

Figure 1. Decomposition rate of *E. camaldulensis* leaf litter samples.
Bars represent standard errors.

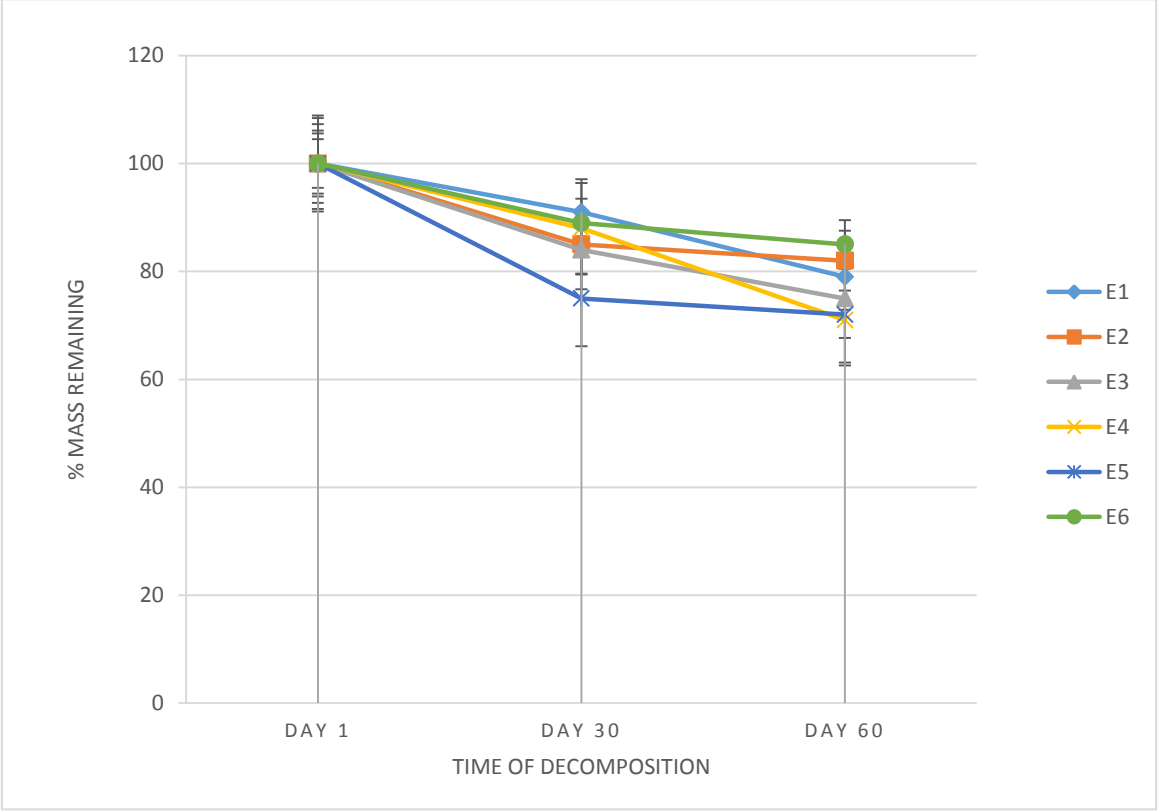

Figure 2. Percentage mass of *E. camaldulensis* leaf litter remaining after different periods of decomposition. Bars represent standard error (SE).

2. 7. Release-immobilization pattern of nutrients through leaf litter and their return to the soil

Perusal of the data presented in Table 2 and 3, show the chemical composition and properties of *E. camaldulensis* leaf litter and soil samples respectively. There was a general decrease in the nutrient status of the leaf litter and an increase of nutrient in the soil during the period of decomposition. Since C:N and C:P have been used as quality indexes of decomposing organic matter in different ecosystems (Brinson, 1977), there was no correlation in the release of nutrients through leaf litter and their return to the soil in terms of C:N and C:P in all the samples (Table 4).

The release of organic carbon through leaf litter and its return to the soil was negatively correlated only in E4 ($r = -0.9978$) as shown in Table 4. Negative correlations were found between nitrogen release through leaf litter and its return to the soil in E1, E2, E5 and E6 with r values (-0.992, -0.9892, -0.9935, and -0.9996) respectively at $P < 0.05$ (Table 4). Table 4 clearly shows that there was a negative correlation between release of phosphorus through leaf litter and its return to the soil in E2 ($r = -0.9899$, $P < 0.10$) and E6 ($r = -0.9976$, $P < 0.05$). Release of potassium through leaf litter and its return to the soil negatively correlated only in E4 with $r = -0.9877$ at $P < 0.10$ (Table 4). E1 ($r = -0.9942$, $P < 0.10$) and E6 ($r = -0.9936$, $P < 0.10$) showed negative correlation of calcium release through leaf litter and its return to the

soil (Table 4). No correlation was found between release of magnesium through leaf litter and its return to the soil.

Table 2. Chemical composition of E. camaldulensis leaf litters during their decomposition.

		mg g^{-1}							
	Decomposition	C	N	P	K	Ca	Mg	C/N	C/P
Sample	time (Days)								
E1	1	555.12	23.67	0.32	0.82	16.78	0.64	23.45	1734.75
	30	520.00	19.89	0.29	0.8	15.34	0.44	26.14	1793.10
	60	452.45	19.00	0.21	0.75	15.11	0.21	23.81	2154.52
E2	1	512.87	22.75	0.41	0.76	14.17	0.52	22.54	1250.90
	30	501.35	20.56	0.28	0.61	13.98	0.41	24.38	1790.54
	60	330.33	17.67	0.25	0.52	11.00	0.13	18.69	1321.32
E3	1	499.97	25.90	0.30	0.85	15.69	0.55	19.30	1666.66
	30	487.53	19.98	0.21	0.81	15.63	0.48	24.40	2321.57
	60	422.76	18.85	0.21	0.63	13.00	0.32	22.43	2013.14
E4	1	539.4	20.86	0.38	0.8	13.34	0.61	25.86	1419.47
	30	504.17	17.64	0.35	0.63	12.02	0.44	28.58	1440.49
	60	500.78	15.00	0.30	0.61	10.54	0.25	33.38	1669.27
E5	1	532.86	21.83	0.43	0.77	14.14	0.52	24.41	1239.21
	30	472.00	18.56	0.37	0.65	13.02	0.46	25.43	1275.68
	60	434.33	18.01	0.29	0.45	11.09	0.45	24.12	1497.69
E6	1	560.05	23.46	0.39	0.72	10.13	0.51	23.87	1436.03
	30	525.42	20.05	0.31	0.55	10.00	0.39	26.21	1694.90
	60	520.15	19.91	0.31	0.46	8.16	0.21	6.13	1677.90

Table 3. Chemical properties of soils during *E. camaldulensis* leaf litter decomposition

Sample	Decomposition time (Days)	(H_2O) pH	mg g^{-1} C	N	P	K	Ca	Mg	C/N	C/P
E1	1	6.5	401.00	19.21	1.45	0.61	6.82	0.26	20.87	276.55
	30	4.6	422.11	22.00	1.92	0.87	9.94	1.24	19.19	219.85
	60	4.5	422.18	22.50	2.20	0.88	10.01	1.25	18.76	191.90
E2	1	7.1	518.00	13.43	1.23	0.32	11.48	0.30	38.57	421.14
	30	5.9	542.34	16.90	1.47	0.50	18.00	0.71	32.09	368.94
	60	5.0	578.42	19.64	1.48	0.55	8.85	0.64	29.45	390.82
E3	1	6.8	437.12	11.34	1.43	0.64	10.20	0.21	38.55	305.68
	30	5.2	444.50	12.92	1.45	0.71	10.86	0.34	34.40	306.55
	60	6.0	449.60	15.93	1.6	0.52	11.02	0.45	28.22	281.00
E4	1	5.8	459.77	15.64	0.82	0.43	5.29	0.56	29.40	560.70
	30	5.6	490.35	18.79	1.87	1.00	11.23	0.60	26.10	262.22
	60	6.3	490.80	19.00	1.90	1.20	10.05	0.71	25.83	258.32
E5	1	7.4	501.22	23.40	1.64	0.91	8.56	0.19	21.42	305.62
	30	7.0	532.90	26.00	1.91	0.94	10.67	0.35	20.50	279.00
	60	4.7	541.79	26.89	1.91	0.94	10.80	0.45	20.15	283.66
E6	1	5.6	419.00	10.01	0.36	0.57	12.13	0.62	41.86	1163.89
	30	6.1	522.78	17.45	0.60	0.70	12.20	0.65	29.96	871.30
	60	6.8	604.45	17.50	0.62	0.73	11.05	0.67	14.54	974.92

Table 4. Correlation analysis between release of nutrient through *E. camaldulensis* leaf litter and return of nutrient to the soil at day 1, day 30 and day 60 of decomposition

	E1		E2		E3		E4		E5		E6	
	r	r^2	r	r^2	r	r^2	r	r^2	r	r^2	r	r^2
Organic carbon	-0.7641	0.5839	-0.9375	0.8788	-0.8879	0.7883	-0.9978*	0.9956	-0.9841	0.9685	-0.9451	0.8931
Nitrogen	-0.9992*	0.9985	-0.9892**	0.9785	-0.8516	0.7252	-0.9168	0.8406	-0.9935**	0.9870	-0.9996*	0.9992
Phosphorus	-0.9203	0.8470	-0.9899**	0.9800	-0.5903	0.3485	-0.8006	0.6409	-0.8220	-0.8220	-0.9976*	0.9952
Potassium	-0.7428	0.5518	-0.9852	0.9707	0.8555	0.7318	-0.9877**	0.9755	-0.7857	0.6173	-0.9855	0.9712
Calcium	-0.9942**	0.9883	0.6839	0.4677	-0.6656	0.4430	-0.7349	0.5400	-0.8115	0.6586	0.9936**	0.9872
Magnesium	-0.8499	0.7223	-0.5975	0.3570	-0.9637	0.9287	-0.9734	0.9475	-0.9667	0.9346	-0.9737	0.9481
C:N	-0.4378	0.1917	0.4674	0.2184	-0.5152	0.2654	-0.8174	0.6681	-0.04121	0.0017	-0.8092	0.6548
C:P	-0.8317	0.6918	-0.8793	0.7732	-0.003541	0.9999	-0.5735	0.3289	-0.4703	0.2212	-0.9559	0.9138

*Significant at 0.05 level, **Significant at 0.10 level

2. 7. 1. Determination of Microbial Activity (CO_2 Evolution)

The Carbon (IV) oxide evolution resulting from the decomposition of the leaf litters of *E. camaldulensis* is shown in Figure 3. The CO_2 evolution varied between 298.0 to 413.0 µg/g/day in E1, 271.1 to 390.5 µg/g/day in E2, 312.4 to 380.7 µg/g/day in E3, 354.4 to 500.0 µg/g/day in E4, 102.4 to 250.9 µg/g/day in E5 and 242.0 to 400 µg/g/day in E6 during the different periods of observation. The maximum evolution of CO_2 was observed on the day 1 in all the samples. The CO_2 evolution was minimum on day 60 in all the litter samples.

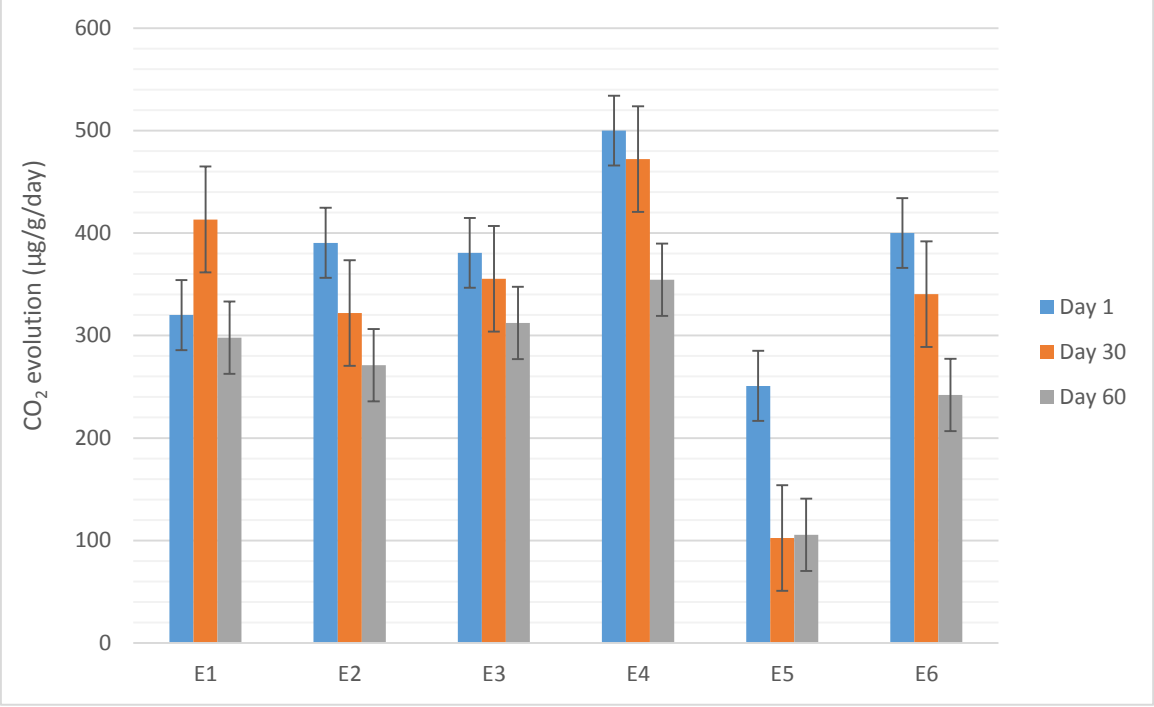

Figure 3. The variation of CO_2 evolution from leaf litters of *E. camaldulensis.* Bars represent standard error (SE).

2. 8. Total viable microbes

Table 5. Association between bacteria ($x10^6$) and fungi ($x10^3$) in *E. camaldulensis* leaf litter Samples

	Day 1	Day 30	Day 60
Bacteria	12.33	14.5	13.5
Fungi	18.5	18.33	13.67
x^2	3.442*	0.9620*	5.583*

Level of significance: *P < 0.05

Perusal of Table 5 shows that there was a significant increase in total viable bacteria with the advancement of decomposition. The total viable bacteria decrease at day 60 in all the samples. Maximum mean bacteria count (14.5 x 10^6 g^{-1}) was recorded at day 30. Fungi count (18.5 x 10^3 g^{-1}) was recorded highest at day 1. As revealed in Table 5, there was an association between total viable bacteria and fungi during the period of decomposition: day 1 (x^2 = 3.442), day 30 (x^2 = 0.9620) and day 60 (x^2 = 5.583).

2. 9. Soil microbiological and physicochemical properties in different plots under exotic plantation during decomposition period

Table 6. Correlation matrix of soil microbiological and physicochemical properties in six plots under *E. camaldulensis* plantation at day 1 of the decomposition study. The soil properties are total viable bacteria (x10^6), total viable fungi (x10^3), CO_2 evolution (mg/g/day), pH, C, N, P, K, Ca and Mg.

	E1	E2	E3	E4	E5	E6
E1						
E2	0.9993*					
E3	0.9967*	0.9986*				
E4	0.9787*	0.9846*	0.9920*			
E5	0.9787*	0.9721*	0.9591*	0.9163^{ns}		
F6	0.9912*	0.9946*	0.9986*	0.9971*	0.9431*	

Level of significance: P < 0.01

Table 7. Correlation matrix of soil microbiological and physicochemical properties in six plots under *E. camaldulensis* plantation at day 30 of the decomposition study. The soil properties are total viable bacteria (x10^6), total viable fungi (x10^3), CO_2 evolution (mg/g/day), pH, C, N, P, K, Ca and Mg.

	E1	E2	E3	E4	E5	E6
E1						
E2	0.9632*					
E3	0.9934*	0.9876*				
E4	0.9999*	0.9658*	0.9945*			
E5	0.7953^{ns}	0.9284*	0.8588^{ns}	0.8008^{ns}		
E6	0.9749*	0.9988*	0.9939*	0.9770*	0.9100^{ns}	

Level of significance: P < 0.01

The soil microbiological and physicochemical properties (Total viable bacteria, total viable fungi, CO_2 evolution, pH, C, N, P, K, Ca and Mg) in six plots under *E. camaldulensis* plantation were analyzed and correlated during the period of decomposition; at day 1, day 30 and day 60.

The pearson's correlation matrix was used to determine relationships among the soil samples in terms of microbiological and physicochemical properties; it reveals that they were positively correlated at day 1 (Table 6) except E5 which did not have a significant relationship with E4 (r = 0.9163). Table 7 shows that at day 30 of the decomposition study, E1, E2, E3, E4 and E6 were positively correlated; E5 had correlation with E2 (r = 0.9284) but did not have significant relationship with E1, E3, E4 and E6 (r = 0.7953, 0.8588, 0.8008 and 0.9100 respectively). Table 8 reveals that at day 60, significant correlation exist among the samples. E5 had no correlation with E1, E3 and E4 (r = 0.8942, 0.8975 and 0.8883 respectively).

Table 8. Correlation matrix of soil microbiological and physicochemical properties in six plots under *E. camaldulensis* plantation at day 60 of the decomposition study. The soil properties are total viable bacteria ($x10^6$), total viable fungi ($x10^3$), CO_2 evolution (mg/g/day), pH, C, N, P, K, Ca and Mg.

E1	E2	E3	E4	E5	E6
E1					
E2	0.9806*				
E3	0.9998*	0.9821*			
E4	0.9997*	0.9783*	0.9996		
E5	0.8942^{ns}	0.9641*	0.8975^{ns}	0.8883^{ns}	
E6	0.9664*	0.9980*	0.9685	0.9633	0.9788

Level of significance: $P < 0.01$

3. DISCUSSION / CONCLUSIONS

In this study, the decomposition of leaf litter of *E. camaldulensis* from different plots under Eucalypt soils were considered. Litter-fall as a source of various compounds and elements, can influence physical and chemical properties of plantation soils and direction of soil-forming processes (Norden, 1994) and consequently soil microbiological properties. Leaf litter breakdown is regulated by exogenous variables such as temperature, nutrient availability and site conditions (Suberkropp and Chauvet, 1995) and by endogenous factors such as litter chemistry. Litter quality, soil microbiological characteristics, soil physicochemical properties and litter chemistry have been considered as an important factor controlling the decomposition rate (Singh et al., 1999; Sundarapandian and Swamy, 1999; Ribeiro *et al*., 2002; Tateno *et al*., 2007). *E. camaldulensis* leaf litter samples from different plots in Eucalypt plantations had different decomposition rate which suggested that soil properties was an important factor for decomposition. Also, this may be because the leaf C:N ratio, which is a good indicator of the decomposition rate (Swift *et al*., 1979; Sundarapandian and

Swamy, 1999; Tripathi *et al*., 2006; Tateno *et al.,* 2007), were different in all the samples. The decomposition rate was highest in E6 because of its C:N ratio. This result is in agreement with the observations of Pandey *et al*. (2007) who found that decomposition rate of Quercus leaf litter was slightly different in plantation sites at the later stage of litter decomposition due to site conditions, and Ozalp *et al* (2007) who reported that water tupelo leaves on the Big and Little Bull Creeks side decomposed faster than on the Pee Dee River side probably due to micro-environmental factors such as temperature, moisture and nutrient availability. Difference in decomposition rate among *E camaldulensis* leaf litter samples may also be attributed to the difference in site fertility. Some studies have shown that leaf litter decay faster on more nutrient-rich stands (Swift *et al.,* 1979).

Despite the fact that there were positive correlations of the different plots in terms of soil microbiological and physicochemical properties during the period of decomposition, the release and return of nutrient to the soil differed. Changes in the chemical properties of different soil and leaf litter samples observed during their decomposition over time varied because of the following: mineralization, presence of foreign substances and changes in microbial population (Norden, 1994; Chen et al., 2011). The decreased organic carbon content of the litter and increase in soil organic carbon could be due to leaf litter decomposition. Similar findings for *sal, teak and eucalyptus* have also been reported by Prasad *et al.* (1991). However, the increase in soil organic carbon content could be attributed to addition of good quantity of leaf litter into the soil (Flaig, 1984). This result is in agreement with the findings of various researchers (Hosur and Desog, 1995; Manhas *et al.*, 1997; Dutta and Dhiman, 2001).

The decrease in nitrogen concentration of the leaf litter with the advancement of decomposition can be attributed to higher demand for nitrogen during the intense microbial activity. The higher nitrogen release from litterbags also lies in the fact that they enrich the litterbags with nitrogen through atmospheric nitrogen fixation and develop more microbial colonies inside the litterbags which therefore degrade the litter material more quickly and hence improve the soil environment (Singh *et al.*, 1998). This finding is in agreement with the results of Kumar and Deepu (1992), who also observed an increase in soil nitrogen and a decrease in litter nitrogen during decomposition of leaf litter of *Casuarina, Acacia* and *Leucaena*. Furthermore, the decrease in litter nitrogen may be due to the adverse climatic conditions and rapid immobilization of nitrogen by microorganisms (Debnath and Hajra, 1972). The litter decomposition provide a stable supply of carbon and energy for microorganisms and cause an increase in the microbial biomass pool, thereby increasing soil respiration rate. This might help to enhance nitrogen availability in the soil (Surekha *et al.*, 2004).

Phosphorus can be release via different patterns, depending especially on its initial concentration and site conditions (Cozzo 1976). During the present study, higher available phosphorus content was observed before the experiment in litter samples of *Eucalyptus camaldulensis.* A significant decline in available phosphorus was recorded at the end of the experiment. The initial higher amount of available phosphorus concentration of decomposing litter may be attributed to biological translocation from deeper soil layers (McBrayer and Cromaek, 1980). The decrease in phosphorus concentration towards the end can be ascribed to high rate of litter decomposition during this study (Arunanchalam *et al.*, 1998). The increase in available soil phosphorus content could be attributed to the production of organic acids during decomposition, thereby increasing the availability of phosphorus in soils (Lal *et*

al., 2000). Furthermore, the increase may also be due to large C:P ratio of leaf litter which are likely to increase the available soil phosphorus content (Shukla and Vimal, 1969). This finding is in agreement with the results of Prasad *et al.* (1991) and Dass *et al.* (1995)

Litter decay is a complex process with marked differences among nutrients in their rates of release. Potassium, magnesium and calcium are among the most mobile nutrients in litter of eucalyptus forests (Attiwill 1968, O'Connell and Grove 1996). However, the non-correlation of potassium release from leaf litter and its return to the soil may be ascribed to lower rate of decomposition of litter and immobilization of potassium by microbes (Nykvist, 1963). The negative correlation between release and return of potassium in E2 and E6 (Table 4) can be attributed to the fact that potassium is not strongly bound in organic structures, unlike that of nitrogen and sulphur. Hence, microbial action is not critical for potassium release as it is for the mineralization of organic bound elements (Hosur and Desog, 1995). This could be one of the reasons for less immobilization as indicated by large release to the available pool (Chaminade, 1955).

The initial increase in Ca concentration in the decomposing litter could be attributed to slower rate of decomposition. Moreover, the leaching of other water soluble substances might have resulted in apparent increase in Ca concentration (Kunhamu, 1994). There was a decrease in Ca concentration of leaf litter and an increase in soil Ca concentration. This result is in conformity with the results of Thomas (1969), who also showed similar results. The higher exchangeable calcium content of soil during litter decomposition may be ascribed to organic matter addition into the soil, which is subsequently released into the soil through decomposition processes by biotic activities than leaching (Blair, 1988). Similarly, the lower calcium content in soil before litter decomposition could be attributed to low organic matter addition into the soil Kumar *et al.* (1998) and can also be attributed to low microbial activities in soil (Surekha *et al.*, 2004).

A decline in Mg concentration of leaf litter during decomposition can be attributed to its requirement by the decomposer organisms for their metabolic activities (Swift *et al.*, 1979). This results are in agreement with the findings of Sivakumar (1992), who made the similar observations. Moreover, the significant increase in soil Mg during decomposition may be due to biological mobilization of Mg into the soil (Staff and Berg, 1982).

Litter nutrient availability can influence decomposer biomass, microbial and enzyme activities (Raubuch and Beese, 1995; Rejmankova and Sirova, 2007). Microbial activity in terms of carbon (IV) evolution was different in all the samples, which suggested that varied nutrient availability affects microbial activities. Interestingly, CO_2 evolution was recorded highest on day 1 of decomposition in all the samples due to the fact that litter nutrient availability was most on day 1 in comparison with day 30 and 60. This findings agrees with Rejmankova and Sirova (2007) who reported that microbial activities are high when litters still have high nutrient availability. This variation in microbial activity between litters may be attributed to the differences in physical and chemical characteristics of the litters, which are known to affect decomposition rates (Swift *et al.*, 1979). According to Singh (1969), the low rate of microbial activity among eucalypt litter samples and also in comparison with *Albizia* and teak might be due to the presence of polyphenols in eucalypt leaves. The hard texture of the leaves may have also offered resistance to microbial activity.

Soil microbial biomass acts as driver for a wide range of soil and ecosystem processes (Bardgett and Straalen 2008; Bardgett and Wardle 2010). The increase in bacterial and fungal population may also be due to the presence of suitable soil moisture and temperature

conditions (Vander, 1963) and production of growth promoting substances by microbes (Jackobsen *et al.*, 1994). *Eucalyptus* produces allelopathic compounds like phenols, tannin, terpene and esters during decomposition (Goya *et al*., 2008) and these compounds can also negatively affected soil microorganisms (Yu *et al*., 2009). However, the noticeable decrease in soil microbial number at the later period of decomposition has consequences for ecosystem services, such as carbon storage and retention of nutrients in soil (Steinbeiss *et al*. 2008; De Deyn *et al*. 2009, Malik *et al.*, 2013). This study suggests that possible toxic compounds from the leaves of *Eucalyptus* must have had a harmful effect on soil microbial biomass (Behera and Sahani, 2003).

The results of this study show that the decomposition rates of *E. camaldulensis* leaf litters in different plots under Eucalypt plantation soils are different. This is due to variation in their soil microbiological characteristics and soil physicochemical properties. Although there is significant correlation between nutrient release from leaf litter and nutrient return to the soil, some elemental nutrients are lost due to microbial activities like anabolism. This finding also suggests that rate of decomposition determines the release of nutrient from leaf litters. There is a strong relationship between total viable bacteria and fungi during decomposition and their number decreased at the later stage of decomposition, which can be suggested that there was a reduction in soluble nutrients and persistence of structural materials like cellulose, lignin etc. With advancement of decomposition, CO_2 evolution decreased due to the decline in the carbon compound of the litter. Difference in chemical composition, decomposition rates and nutrient release dynamics during decomposition of leaf litter can influence nutrient balance, soil organic matter accumulation and soil chemistry.

Thus, it is advisable to conduct such similar studies in different eco-climatic zones for evolving strategies for the management of various forestry species.

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