Journal of Biology, Agriculture and Healthcare
ISSN 2224-3208 (Paper) ISSN 2225-093X (Online)
Vol.3, No.16, 2013

Rates of Decomposition and Nutrient Release from Biomass of Various Species of Tropical Legume Cover Crops in Dryland Soils of Eastern Indonesia

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Abstract
The contribution of various species of tropical legume cover crops used in the dryland tropics of Indonesia to increase organic matter and plant nutrients in the soils is generally unknown. A pot experiment arranged in the field were conducted to study the rates of decomposition and nutrient release from these cover crops. The factorial experiment was designed as a randomized complete block with two treatment factors and three replications. The first factor was species of legume cover crops viz. *Centrosema pubescens* L., *Mucuna pruriens* L., *Crotalaria usaramoensis* L., and *Phaseolus lunatus* L., and the second factor was methods of placement of biomass (in litter bags) either placed on the soil surface or embedded in the soils. The rates of decomposition and nutrient release were higher in biomass embedded in the soils which were 0.303 (2.76 year^{-1}), 0.264 (2.41 year^{-1}), 0.187 (1.71 year^{-1}) and 0.104 (0.95 year^{-1}) for *C. usaramoensis* L., *P. lunatus* L., *M. pruriens* L. and *C. pubescens* L., respectively. Nutrient release (N, P, K, Ca) from *C. usaramoensis* L. and *P. lunatus* L.embedded in the soils reached a half time (more than 50%) of 20 days while those from *M. pruriens* L. and *C. pubescens* L. did that of 30 days. *Crotolaria usaramoensis* and *Phaseolus lunatus* had the high, *Mucuna pruriens* had the medium and *Centrosema pubescens* had the low biomass quality. It was concluded that the use of *C. usaramoensis* L. and *P. lunatus* L. embedded in the soil 10-20 days before planting, will be the apropriate methods to amend soil properties in the dryland tropics.
Keywords: Legume cover crops biomass, The rates of decomposition and nutrient release

1. Introduction

In the dry tropics of Indonesia, generally the land is left fallow in the dry season due to the scarcity of water. The high daily air temperatures in the areas led to a high decomposition and mineralization of organic matter. Evaporation of nutrients from the soil surface or leaching of nutrients during the rainy season as also absorption by plants during the growing season have resulted in their low content in the soils. The high price of chemical fertilizers preclude their use by subsistence farmers who then resolve to the use of legume cover crops.

Legume cover crops have been used by farmers in the tropics and are the hub of soil management of subsistence farmers to increase crop yields. Legume cover crops decrease soil surface temperatures, decrease evaporation from the soil surface, increase soil organic matter and nutrients especially nitrogen, and decrease soil bulk density.

Various species of tropical legume cover crops are used depending on the availability of the seeds at planting or the availability of standing cover crops available nearby. Species such as *Centrosema pubescens*, *Mucuna pruriens*, *Crotalaria usaramoensis*, *Phaseolus lunatus*, *Leucaena leucocephala*, *Sesbania grandiflora*, *Glyricidia* sp., have been used. The plants are cut from specially planted plants in situ or cut and carried from elsewhere which are then spread on the soil surface or plough into the soils. This practice will depend on the availability of the seeds as well as labour at planting time.

The microbial decomposition of plant biomass in the soil depend on microbial population, microclimates of the soils viz. soil temperature, soil aeration, soil water, soil pH and plant materials. In the plant materials include plant age, chemical composition, C/N ratios, and lignin and polyphenols content (Handayanto, 1997; Hartemink & O'Sullivan, 2001; Berge & McClaugherty, 2002; Oladoye *et al*., 2005; Shimamoura & Momose, 2005).

The rate of decomposition as also the extent and rates of nutrients release from various species of legume cover crops used in the dry tropics of Indonesia are generally unknown. An experiment was conducted to answer these problems.

2. Materials and Method

A pot (10 kg plastic bags) experiment to study the rates of decomposition of legume cover crops (LCC) was conducted during the dry season from July to August 2012 at the annual crop farming field at the village of

Oelnasi, Kupang regency, NTT province, Indonesia at an elevation of ca. 200 m above sea level. The region has a B climatic type (Oldeman classification), with the soil temperatures at the soil surface and at 5 cm depth of 34.92 and 28.68 ^{o}C, respectively. During the experiment there was no rainfall experienced in the areas.

The decomposition rates of LCC were tested using the method of litter bag technique developed by Anderson (1983) and Ribeiro *et al*. (2002). Litter bags were made from nylon wire mesh (2.0 mm mesh) with the size of 35 cm x 35 cm.

The experiment was a 4x2 factorial experiment in a randomized block design with three replications. The first factor was four LCC which were *C*. *pubescens* L., *M*. *pruriens* L., *C*. *usaramoensis* L., and *P*. *lunatus* L., and the second factor was placement of the litter bags which were either at the soil surface or embedded at 15-20 cm soil depth.

Samples of LCC biomass were air dried and then oven dried at 70^{o}C for 48 hours. Chemical analysis was conducted for carbon (Walkley & Black method), nitrogen (Kjeldahl method), phosphorus, potassiun, calcium, and magnesium content using spectrophotometer after wet digestion with $HClO_4$ and HNO_3 (Sulaeman *et al*., 2005). Lignin and polyphenol contents were also analysed with the method of ADF& Follin-Denis (Anderson & Ingram, 1989).

Sufficient number of litter bags were filled with 100 g dry weight of LCC and placed on the soil surface or embedded in the soil inside a polybag in line with the treatments. Monitoring of the polybags were conducted at day 0, 10, 20, 30 and 40 (Haraguchi *et al*., 2002; Maswar, 2005). Once the litter bags were taken from the soils, the biomass samples left in the litter bags were carried to the laboratory for chemical analysis in a manner previously described.

During the experiment the following variables measured were weight loss and nutrient release of LCC and rate of decomposition of LCC biomass.

2.1 Weight loss and nutrient release of LCC

Weight loss and nutrient release of LCC was calculated using the equation (eq.1 and 2) of Guo & Sims (1999), Sulistiyanto *et al*. (2005) and (Maswar. 2005) as follows:

$$L\ (\%) = \frac{(W0 - Wt)}{Wo} \times 100 \qquad (1)$$

and

$$R\ (\%) = \frac{(WoCo - WtCt)}{WoCo} \times 100 \qquad (2)$$

where. L= the loss of biomass weight; Wo = biomass weight before the application; Wt: biomass oven-dry weight left after t time; R= released nutrient; Co= nutrient concentration (mg kg^{-1}) in the initial biomass; Ct= nutrient concentration (mg kg^{-1}) in the remaining biomass.

2.2 Rate of decomposition of LCC biomass

Prediction of rate of biomass decomposition was conducted using the equation (eq.3) of Guo &Sims (1999), Ribeiro *et al*. (2002), Rogers (2002) and Sulistiyanto *et al*. (2005) that assumes the weight loss occured exponentially:

$$W_t = W_o\, e^{-kt} \qquad (3)$$

where Wt= weight of biomass/litter after a period of observation (g); Wo = initial biomass/litter weight (g); e = logarithm value; k = logarithmic coefficient (constant) of decomposition rate; t = observation period (day).

Using MSTATC computer program data obtained were subjected to the analysis of variance after transformation where necessary. When treatment effects were significant the analysis was continued with mean separation using Duncan's Multiple Range Test (Gomez & Gomez, 2007).

3. Results

3.1 Initial chemical content

The biomass of CU and PL had initially higher content of chemicals and C/N and C/P ratios compared with CP and MP, while their lignin and polyphenol contents were lower (Table 1).

3.2 Weight loss

Interaction between species of LCC and methods of litter bag placement was significant. The weight losses increased with time, with CU and PL had higher weight loss compared to MP and CP starting on day 20 especially in those incorporated in the soils (Figure 1).

3.3 Nutrient Release

Overall the magnitude of the nutrient release vary between LCC biomass and between litter bag application method. The magnitude of the nutrient released in this experiment increased significantly with increasing decomposition time period. Nutrient (organic-C, N, P, K and Ca) concentrations released from all kinds of LCC biomass significantly increased in both application methods (Table 2). The CU and PL biomass incorporated in the soil released higher but were not significantly different C, N, P, K and Ca concentration from day 10 to day 40 compared with MP and CP biomass.

Based on the initial result of the chemical analysis of the elements C ,N, P, K and Ca (Table 1) it can be concluded that C is the largest constituent element of plant biomass in the appeal of other elements. In this study the amount of the C elements released varied between LCC biomass and methods of application.

The C element released since the perode of 10-40 days increased steadily and significantly different for all LCC biomass. Up to period of 40 days the amount of C released from LCC incorporated in the soil reached 97.07% of 392.2 g C kg^{-1} for CU and reached 95.51% of 427. 2 g C kg^{-1} for PL and significantly higher than MP (88.62% of 460.6 g C kg^{-1}) and CP (68.82% of 432.8 g C kg^{-1}) (Table 2).

Similarly, N, P, K and Ca elements shows different trends and increased until the period of 40 days (Table 2). After 20 days of decomposition, the average amount of nutrient (N, P, K. and Ca) released from CU and PL biomass had achieved the half-life (t_{50}) which meant that 50% of initial nutrients concentration had been released from the respective biomass, i.e. N (64.1% and 60.21%), P (64.50% and 64.40%), K (58.81% and 56.47%) as well as Ca (65.57% and 63.41%). The value of t_{50} for MP and CP at the same application method were achieved at 30 days.

3.4 Rate of decomposition

The value of the rate of decomposition (*k*) of several different types of LCC biomas and litter bag application methods during a period of decomposition are presented in Figure 2.

The average rate of decomposition of the LCC biomass types and litter bag application methods differed significantly at each time of observation. The highest rate of decomposition was shown by CU and PL embedded in the soil, starting at day 10 until the day 20. The rate of decomposition reached consecutively 0.041 (0.0041 day^{-1} or 1.49 $year^{-1}$), 0.039 (0.0039 day^{-1} or 1.42 $year^{-1}$) which were significantly higher than other biomass. After a period of 30 days, the rate of decomposition of embedded CU biomass increased sharply from the *k* value of 0.148 (0.0048 day^{-1} or 1.8 $year^{-1}$) to 0.303 (0.0075 day^{-1} or 2.76 $year^{-1}$) in the 40-day period of decomposition. PL followed with the *k*-value of 0.130 (0.0043 day^{-1} or 1.57 $year^{-1}$) in the period of 30 days and increased to 0.264 (0.0066 day^{-1} or 2.41 $year^{-1}$) in the period of 40 days (Figure 2). Whereas MP biomass with the same treatment (incorporation) and the same period (40 days) were 0.187 (0.0047 day^{-1} or 1.71 $year^{-1}$) and followed by CP with lower rate of decomposition of 0.104 (0.0026 day^{-1} or 0.95 $year^{-1}$).

The rate of decomposition of biomass placed on the soil surface tends to be slower and not significantly different among all species of LCC biomass (Figure 2). Until the 40^{th} day, the rates of decomposition were not significantly different among CU, PL, MP and CP biomass with consecutive rates of 0.073 (0.002 day^{-1} or 0.73 $year^{-1}$), 0.064 (0.59 day^{-1}), 0.059 (0.54 day^{-1}) and 0.054 (0.001 day^{-1} or 0.50 $year^{-1}$).

3.5 Total of microbe colony after decomposition

The average total microbe colony in the soil was affected by the interaction between types of LCC biomass and methods of biomass application. Treatments of CU and PL biomass embedded in the soil showed higher total colony, $28x10^6$ *cfu* and $24x10^6$ *cfu* respectively, followed by MP ($22x10^6$ *cfu*) compared with the other treatments (Table 3). The placement of LCC biomass on the soil surface resulted in lower total microbe colony.

4. Discussion

Biomass decomposition will basically cause changes in condition in the soil due to the influence of biological and abiotic factors. The decomposition of LCC biomass is an important aspect in nutrient cycle due to its determination on the level of the cycled nutrients becomes available to plants.

Weight loss (level of decomposition) of biomass during decomposition period is an indicator to estimate the rate of decomposition. Results of the present study indicated that the weight loss of biomass occurred very fast in 40 days of decomposition and were significantly different among LCC biomass and methods of biomass (in litter bags) application (Figure 1).

The highest weight loss of biomass was shown in all embedded biomass compared to those placed on the soil surface (Figure 1). CU and PL biomass embedded (in litter bags) in the soils, had shown their higher weight loss (10.47% and 9.42% respectively) since the day 10. Those weight lossess significantly increased up to day 40 with the achieved loss of 93.63% and 91.07% of initial dry weights respectively compared to MP and CP.

These conditions were due to higher biochemical quality (N, P, K, and Ca contents) but lower C/N and C/P ratios of the two types of biomass. The critical values of those ratios for mineralization process were <20 and <200 respectively. In addition to that, lignin and polyphenol contents in CU and PL were lower, resulted in faster rate of decomposition and mineralization to release nutrients to the soils.

High lignin and polyphenol contents in organic materials will hamper the mineralization process due to their ability to bind proteins, thus determine the quality of organic materials to be decomposed by soil microbes (Stevenson, 1982; Hadyanto *et al*., 1997). Torreta & Takeda (1999) and De Costa & Atapattu (2001) reported that weight loss of biomass has generally taken place in the first 2-4 weeks, since the physical and biological process occurred faster at this level and most of the weight loss came from soluble compared to lignocellulose fractions (Andren & Paustin, 1987). Soluble fractions of the biomass mostly have simple organic compounds

such as glucose, phenols and amino acids (Suberkropp *et al*., 1976), while the insoluble ones (lignocelluloses) generally consist of lignin, cellulose and xylem (Andren & Paustin, 1987).

Besides the bio-chemical composition of biomass, the environment factor particularly soil temperature and moisture also influence the rate of biomass decomposition. The average soil temperature during the period of decomposition was 34.92^{0}C at the soil surface of 0-5 cm and 27.68^{0}C at the 15-20 cm depth, while the humidity was 55%. Embedding resulted in more stable daily soil temperature and moisture, which favour the activities of decomposing microbes. The average colony of microbes recorded in the embedded treatment increased up to 22x10^6 cfu compared to the soil surface one, which only achieved 17x10^4 cfu (Table 3). The increased in total colony of microbes positively affected the rate of decomposition. On the contrary, the placement of biomass on the soil surface resulted in lower weight loss and rate of decomposition due to higher fluctions of soil temperature and moisture, which will inhibit the activities of decomposing microbes. Although soil fauna activity was not measured in this present experiment, visual observation indicated that embedded method of biomass application was able to increase the activities of soil fauna as supported by the better environment. This optimum condition would be able to increase their activities in decomposing organic materials. According to Sutedjo *et al*. (1991), the optimum condition is pH of 5.5-7.5, optimum soil temperature of 20-28^{0}C and soil moisture of 50-60%.

Pattern of nutrient release from several types of LCC biomass increased in line with the weight loss, which meant that the greater the weight loss of biomass the greater the nutrient released into the soils. Results of this present study showed that the release patterns of C, N, P, K and Ca during the period of decomposition were significantly different among biomass species in both application methods of biomass (placed on the soil surface or embedded in soil) (Figure 2).

In this present study the amount of C-element release was different among the LCC biomass and methods of biomass application. The magnitude of C-element release was associated with nutrients released into the soils. Similarly, the release of N, P, K, and Ca nutrients showed different trend and increased up to the day 40 (Table 2). After 20 days of decomposition, the average amount of nutrients (N, P, K, and Ca) released from CU and PL biomass embedded in the soil have reached the half time (t_{50}), meaning that 50% nutrients have been released from the initial concentration of biomass at the time of incorporation. Whereas MP and CP biomass, at the same method of application, reached the half time at day 30.

Rate of decomposition recorded in this present study showed significant differences among types of LCC biomass and methods of their application. In most decomposition experiments, the constant of yearly rate of decomposition (k year^{-1}) is often used to compare rate of decomposition between species or to determine the effects of environment. Generally, the high k value indicates the rate of decomposition of plant biomass. In this present study, the embedded CU and PL species decomposed faster during 40 days of decomposition period, as indicated by their k values of 2.76 year^{-1} and 2.41 year^{-1} respectively (Figure 2), which were significantly higher than MP (1.71 year^{-1}) and CP (0.95 year^{-1}). These results were in line with those of De Costa & Atapattu (2001) conducted in Sri Lanka on species of Caliandra (2.65 year^{-1}) and Flamengia (1,74 year^{-1}), while results of research conducted by Sulistiyanto *et al*. (2005) conducted on the species of mixed litter on forest soils, reached k value of 0.285-0.396 year^{-1}. The increased rate of decomposition of CU and PL was due to their higher biomass moisture content compared to those of CU and PL. The higher ability to absorb water of CU and PL biomass were associated with their finer and softer leaf textures and also supported by their high bio-chemical quality, which made them easily to decompose.

The reasons for the differences in k values among types of biomass and methods of application in this present study, were (1) the different quality of biomass material mainly bio-chemical composition (especially C, N, P, K, Ca, C/N and C/P ratio) as well as the content of lignin and polyphenols of different LCC, which determined the rate of decomposition; (2) different environmental conditions of soils, as the site of biomass placement, especially temperature and soil moisture, which affected microbes including fungi activities (Saetre. 1988; Rao, 1994). It has been found that the biomass species that have high N contents will decompose more quickly than those with low content of N. In this study, the rates of decomposition of LCC biomass were also significantly different and increased in line with period of decomposition. This explains that different species and methods of biomass application have different decomposition rates (Temel, 2003).

5. Conclusion

Based on the results of this present study it can be concluded that the quality of LCC biomass were different and determined the rate of decomposition and nutrient release from the plant biomass into the soil. The best method of application was the incorporation of biomass (in litter bags) in the soil due to its ability to increase the rate of decomposition and nutrient release. Biomass of *Crotolaria usaramoensis* (CU) and *Phaseolus lunatus* (PL) incorporated or embedded in the soil decomposed faster with the rate of 0.303 (0.0075 day^{-1} or 2.76 year^{-1}) and 0.264 (0.0066 day^{-1} or 2.41 year^{-1}) and had been able to release nutrients N, P, K, Ca more than 50% on the day

20 compared with MP and CP biomass. *Crotolaria usaramoensis* and *Phaseolus lunatus* had the high, *Mucuna pruriens* had the medium and *Centrosema pubescens* had the low biomass quality. The results of this research is expected to be used as a reference in the management of legume cover crop biomass *in-situ* as a source of green manure in dry land farming.

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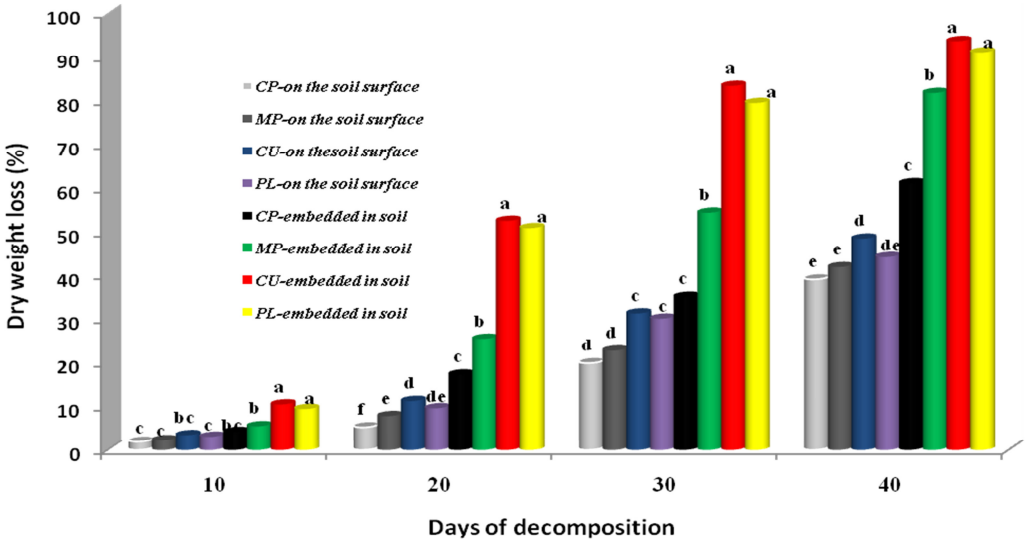
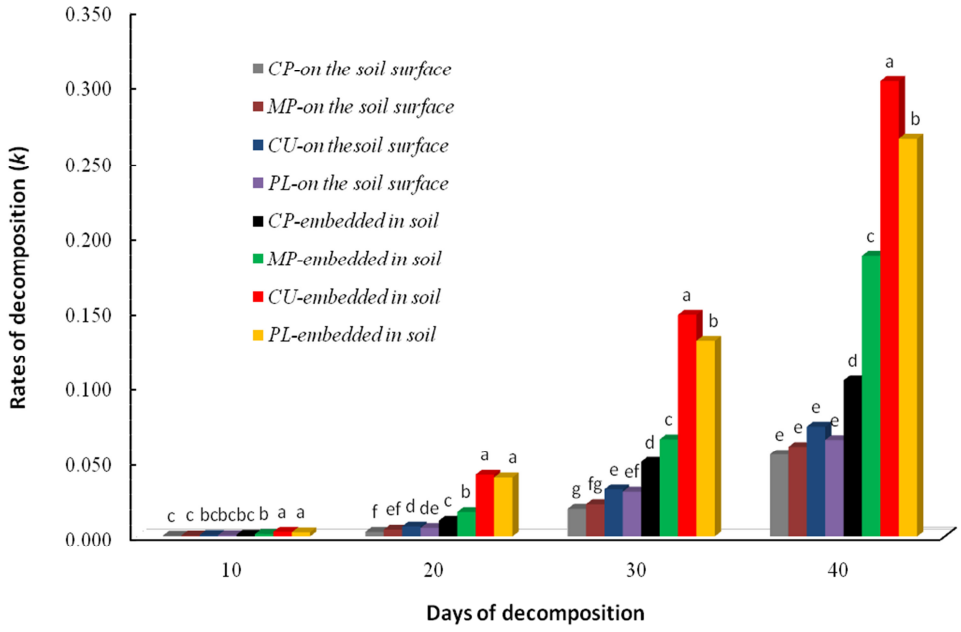


Notes: Bars with the same notation on each period of decomposition were not significantly different at 5% Duncan's Multiple Range Test

Figure 1. The effects of interaction between species of LCC and methods of litter bag placement in the soil on dry weight loss.



Notes: Bars with the same notation on each period of decomposition were not significantly different at 5% Duncan's Multiple Range Test

Figure 2. The effects of interaction between species of LCC and methods of litter bag placement in the soil on

rates of decomposition.

Table 1. Initial chemical content of tropical legume cover crops (LCC)

Parameter	Types of LCC			
	C. pubescens (CP)	*M. pruriens* (MP)	*C.usaramoensis* (CU)	*P. lunatus* (PL)
Chemical components				
a. Moisture content (%)	56.43	70.28	72.06	70.35
b. Total N (%)	2.14	3.21	4.19	3.98
c. Total P (%)	0.12	0.15	0.25	0.37
d. Total C (%)	43.28	46.06	39.22	42.72
e. C/N	20.22	14.35	9.36	10.73
f. C/P	360.67	307.94	156.88	115.46
g. K (%)	0.96	0.98	0.39	1.37
h. Ca (%)	2.67	2.67	3.58	3.56
i. Mg (%)	0.11	0.14	0.03	0.42
j. Lignin (%)	17.64	11.52	9.64	11.36
k. Polyphenols (%)	10.32	7.86	3.76	4.01

Table 2. The average percentage of nutrient released during decomposition of LCC biomass under different LCC types and application methods of litter bag during the decomposition period

Day	Treatments	Percentage of nutrient release				
		C-Org	N	P	K	Ca
		..... %				
10	CP-on the soil surface	2.30^{c}	1.92^{c}	1.46^{c}	2.50^{d}	2.20^{e}
	MP- on the soil surface	3.20^{c}	2.90^{c}	1.92^{c}	3.42^{d}	3.91^{e}
	CU- on the soil surface	5.85^{c}	6.84^{bc}	7.95^{bc}	6.6^{3cd}	5.35^{-de}
	PL- on the soil surface	5.25^{c}	6.22^{bc}	6.66^{bc}	4.49^{d}	8.32^{cd}
	CP- embedded in soil	7.05^{c}	5.73^{bc}	11.94^{ab}	6.96^{cd}	8.97^{c}
	MP embedded in soil	12.36^{b}	10.60^{b}	14.60^{ab}	10.88^{bc}	15.50^{b}
	CU- embedded in soil	18.87^{a}	20.53^{a}	20.36^{a}	17.65^{a}	22.42^{a}
	PL- embedded in soil	16.73^{ab}	21.10^{a}	19.55^{a}	14.82^{ab}	20.05^{a}
20	CP-on the soil surface	8.88^{e}	10.97^{e}	13.67^{e}	8.96^{e}	7.46^{e}
	MP- on the soil surface	10.94^{e}	11.05^{e}	19.85^{de}	11.29^{de}	11.28^{e}
	CU- on the soil surface	16.31^{de}	17.49^{d}	22.96^{d}	16.93^{d}	17.46^{d}
	PL- on the soil surface	18.88^{cd}	16.84^{d}	21.34^{d}	14.05^{de}	16.17^{d}
	CP- embedded in soil	25.25^{bc}	30.00^{c}	34.44^{c}	24.22^{c}	27.95^{c}
	MP embedded in soil	32.10^{b}	35.66^{b}	42.92^{b}	34.26^{b}	45.65^{b}
	CU- embedded in soil	57.55^{a}	64.1^{a}	64.50^{a}	58.81^{a}	65.57^{a}
	PL- embedded in soil	58.04^{a}	60.21^{a}	64.40^{a}	56.47^{a}	63.41^{a}
30	CP-on the soil surface	24.32^{e}	30.6-^{d}	39.39^{d}	29.05f	28.79^{e}
	MP- on the soil surface	26.88^{e}	32.61^{d}	47.91^{d}	38.70e	26.46^{e}
	CU- on the soil surface	36.23^{d}	41.91^{c}	52.31^{cd}	40.71e	36.45^{d}
	PL- on the soil surface	39.68^{d}	39.97^{c}	48.63^{d}	38.95e	35.28^{d}
	CP- embedded in soil	51.87^{c}	66.11^{b}	64.57^{c}	52.91d	54.23^{c}
	MP embedded in soil	62.46^{b}	67.79^{b}	78.92^{b}	71.69c	75.41^{b}
	CU- embedded in soil	89.80^{a}	91.00^{a}	95.09^{a}	91.54a	90.95^{a}
	PL- embedded in soil	87.45^{a}	89.84^{a}	90.69^{ab}	84.10b	87.33^{a}
40	CP-on the soil surface	44.00^{e}	48.81^{d}	50.20^{e}	46.52^{e}	45.94^{f}
	MP- on the soil surface	47.09^{e}	50.48^{d}	61.90^{d}	55.74^{d}	45.62f
	CU- on the soil surface	58.14^{d}	60.51^{c}	66.02^{d}	61.37^{c}	57.01^{d}
	PL- on the soil surface	56.19^{d}	59.50^{c}	61.06^{d}	58.69^{cd}	52.69^{e}
	CP- embedded in soil	68.82^{c}	81.58^{b}	77.97^{c}	63.99^{c}	71.12^{c}
	MP embedded in soil	88.62^{b}	93.25^{a}	84.66^{bc}	77.25^{b}	89.82^{b}
	CU- embedded in soil	97.07^{a}	97.44^{a}	98.23^{a}	97.38^{a}	97.77^{a}
	PL- embedded in soil	95.51^{a}	94.95^{a}	95.94^{ab}	98.40^{a}	95.85^{a}

Notes: Figures followed by the same letter in the same treatment and the same coloumn are not significantly

different at 5% Duncan's Multiple Range Test.

Table 3. Average of total of microbe colony 40 days after decomposition of LCC biomass as affected by interaction between types and methods of biomass (in litter bag) application

Types of LCC biomass	Methods of biomass application	
	On the soil surface	Embedded in soil
	……cfu……	
CP	$7.67x10^{4\ f}$	$16.67x10^{5\ c}$
MP	$11x10^{4\ e}$	$22x10^{6\ b}$
CU	$25.33x10^{4\ d}$	$28x10^{6\ a}$
PL	$24.67x10^{4\ d}$	$24x10^{6\ ab}$

Notes: Figures followed by the same letter are not significantly different at 5% Duncan's Multiple Range Test.