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Advances in Bioresearch

## ORIGINAL ARTICLE

# Effects of *Rhizobium* Inoculation and Cropping systems on Leaf Litter Decomposition of Two legumes (Common bean and Lablab)

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**ABSTRACT**
*Crop litter residues decompose and provide nutrients in to the soil. Decomposition is a process which is accelerated by sufficient soil conditions (good soil physical properties, soil moisture and microorganisms) and residues litter quality. However, the quantitative knowledge on decomposition of different legumes under such conditions when litter residues are placed above and below (10 cm) soil is insufficient. Therefore, the decomposition study of the two inoculated legumes residues, common bean (P. vulgaris) and lablab (D. lablab) collected from two cropping seasons (2015-2016) was set using litterbag experiments at the screen house of Selian Agricultural Research Institute (SARI). The residues were applied on the surface and on sub soils and then retrieved after 10, 20 and 30 days. The parameters determined from the legume residues included; mass loss, decay rate constant (k), and Carbon and Nitrogen concentrations. Results showed lower decomposition of legume residues collected from two cropping seasons when the litterbags were placed on the soil surface compared to subsoil. Mass loss was higher in Rhizobium inoculated legumes than uninoculated legumes of residues collected from both cropping seasons. D. lablab had higher mass loss than P. vulgaris on the soil surface and in sub soil of litter residues collected from both cropping seasons. The residues decay rate ranged from 0.97 to 0.99 for all treatments in screen house across the litter residues collected from the two cropping seasons. Lablab recorded the high decomposition rate than common bean in all sampling times as a result of high initial N and C content in the litter residues. This predicts that, the mass loss, nutrient content, and litter quality were all changed mostly in the first 0-30 days, which indicates that early stage of litter residues incorporation is important in nutrients release into the soil. These findings showed the effect of plant residues on the supply of mineral N to crops growing during subsequent seasons.*
***Key words:*** *C: N ratio, decomposition, legume residues, litterbags, mass loss*

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## INTRODUCTION

The soil fertility levels have been severely depleted during the cropping cycle in sub Saharan Africa [1]. In cropping systems involving legumes, litter residues decomposition may provide substantial amount of nitrogen (N) for subsequent crops [2]. The organic matter and nutrients added to the soil through the process of leaf litter decomposition would be reused by the plants. These nutrients may contribute to the sustainability of soil fertility, which is becoming an important phenomenon for cropping systems. A study by Arunachalamand and Singh [3] indicated that the chemical composition of litter is an important driver of legumes decomposition and nutrient release in to the soil. This is a biological process which is mediated mostly by abiotic factors such as climate, soil characteristics, quality of decomposing organic matter through their effects on soil fauna as the most important factors regulating leaf litter decomposition [4]. A considerable amount of nutrients are returned to the soil through litter fall which has an important role in the biogeochemical cycling of nutrients [5]. However, the amount of nutrient addition through litter decomposition varies from species to species [6]. It is estimated that the nutrients

released during leaf litter decomposition can account for 69-87% of the total annual requirement of essential elements for forest plants [7]. Legumes litter decomposition has been used to determine which characteristics of litter quality are the best predictors of decomposition rates. A study by Lie et al. [8] reported that initial N content and C: N ratio was the first leaf litter chemistry parameters used to predict the rate of legumes decomposition. Most of the crops especially legumes with its high N content, ends up in litter [9].

Although the leaf litters decomposition rates are controlled by three main factors: temperature, moisture, and leaf litter quality [10], the litter quality is said to be the most important determinant of decomposition rates in a given area. Legumes *Rhizobium* inoculation improve the nutrients contents in legumes plant hence litter quality of the plant which determine the decomposition rates. A study by Cayuela et al. [11] suggested that decomposition is controlled by two phases, the first phase of the decomposition process (< 30% of initial mass loss) was regulated by the nutrient content, while the second phase was regulated by the lignin content and the ratio of holocellulose and lignin. Periodically there have been a tendency of smallholder farmers to grow their crops during the rainy season and legume residues are available at the end of the dry season [10]. Thus, residue needs to undergo decomposition for subsequent nutrient release during crop growth. It is expected that, decomposition of crop residue to be low and accumulate during the dry season because surface residues easily dry up; hence, decomposition is hampered by periodical or constant low moisture content [12]. Also, lack of sufficient microbial activity during dry season lower decomposition rate and therefore the residue can both be incorporated into the soil immediately after harvest, or left on the surface through the dry season and then incorporated into the soil just before planting of the next crop [10]. This is for the enhancement of net N mineralization for growth of the subsequent crop. Asgharipou and Rafiei [13] reported the importance of tissue chemistry between surface-mulched and subsoil-buried residue decomposition to be different, possibly due to the microbial decomposer communities on the surface versus in the soil. Inadequate work has been carried out in different cropping systems of *Rhizobium* inoculated legumes to investigate the decomposition process of leaf litter and to estimate the influence of different parameters of these legumes on decay rates and mass loss at different stages of the decomposition. Therefore this study aimed to determine the decomposition rate of different legumes litter residues when placed above and below soil (10 cm) as influenced by *Rhizobium* inoculation and cropping systems in northern Tanzania.

## MATERIALS AND METHODS

### Description of the research experimental site

The screen house experiment was conducted at Selian Agricultural Research Institute (SARI) in northern part of Tanzania using legumes leaf litter residues obtain from two cropping seasons (2015-2016). SARI lies at Latitude 3º21'50.08"N and Longitude 36º38'06.29"E at an elevation of 1390m a. s. l. with mean annual rainfall of 870 mm. The mean maximum and minimum temperature ranges from 22ºC to 28ºC and 12ºC to 15ºC respectively.

### Legume residue collection and preparation

Legume leaf litter residues of common bean (*Phaseolus vulgaris*), and lablab (*Dolichos lablab*) were collected at harvesting time from the field experimental site conducted at Selian Agricultural Research Institute (SARI) farm in the two cropping seasons (2015 to 2016). The plant leaf litter samples were proportionally homogenized and included for the litterbag experiment. However, the stems of legumes were not included for the study due to its woody and lignified nature. The leaf litter residues were air dried and subsequently oven dried (40 °C for 48 h). A 5-g leaf biomass was put in a polyvinyl net bag with a size of 12 cm×15 cm with 2-mm size net. The total number of litter bags for each residue type and experimental site was 360, of which 180 were placed on the surface and 180 were buried (10 cm) below the soil surface. This allowed three replicates to be taken from each treatment at each time of sampling.

**Plate 1:** Fallen litter residues in the field experiment at harvest collected for screen house experiment

**Setting litterbags experiment with legume residues**

Litterbag experiments were set out on fixed plot (size of 3 m×3 m) in the screen house. In general, the experiment was organized in randomized complete block design with factorial arrangement of 5×2×2, five cropping systems (cropping systems 1, 2, 3, 4 and 5), two types of legume residues (common bean and lablab) and two methods of placement (surface and subsurface). The litterbags were placed on the soil surface (0 cm) and buried (10 cm deep). Litterbags were retrieved for weight determination at the intervals of 10 days and N analysis after 30 days. The retrieved bags were cleaned of adhering soils and other (extraneous) materials, and air dried. Subsequently the residues were oven dried (40 °C for 48 h) and reweighed to determine the amount of mass loss and N in some cases.

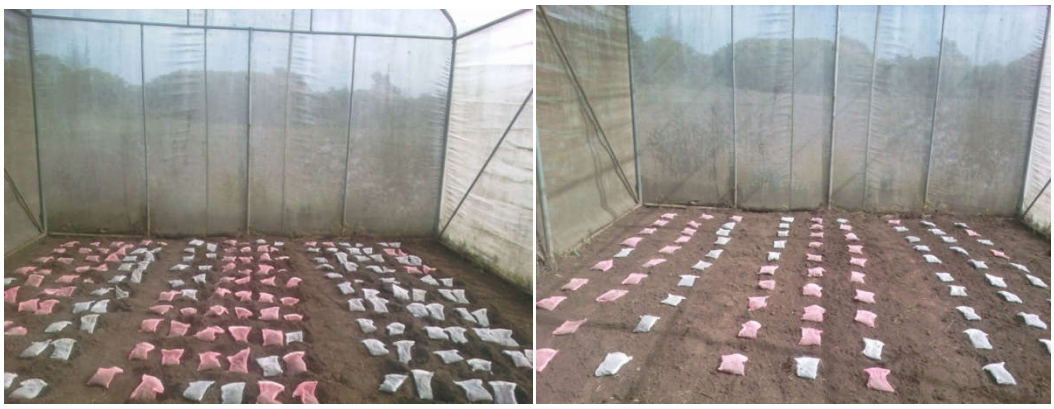


**Plate 2:** Layout of residues decomposition experiment on soil and subsoil in screen house

**Soil and legume residue nutrients analysis**

The soils of the screen house (0–20 cm depth) were analyzed for organic carbon and total nitrogen based on standard procedures (Table 1). The soil pH ($H_2O$) was determined in a solution of 1:2.5 soil water ratio while the soil texture was estimated by the pipette method. Prior to chemical analyses of legume residues, the oven dried residues were ground to a fine powder in a grinding machine to pass a 1-mm size sieve. The residue sample was then weighed 3g and rolled in tin cups for the carbon and nitrogen analysis. Peach ranging from 0.5g to 3g was used as a standard for this purpose. Residues nutrient concentrations (carbon and nitrogen) were determined prior to litterbag setting 0 day and nitrogen was repeated after 30 days of litterbag sampling due to budgetary reasons. Total N contents of the residues were determined by Kjeldhal digestion, distillation and the titration method [14]. Wet digestion method was used for organic C analysis [15]. The C: N ratio was used as a proxy for litter quality.


**Plate 3:** Surface and buried litter bags retrieved after 30 days incubation

**Dry mass remaining and decomposition rate constant (k)**

Mean % dry mass (DM) remaining was calculated from the decay curve as follows:

$$\%M_r: 1- [(M_0-M_t)/(M_0)]*100$$

$\%M_r$= percent mass remaining

$M_0$= initial DM, the mean DM from the handling loss leaf packs.

$M_t$= final DM, the mean DM from each collection date.

The mean %DM remaining for each collection date was used

The decomposition rate constant (k), was calculated from the decay curve as follows:

$\ln ( M_0 / M_t ) = k * t$, where;

$M_0$ = mass of litter at time 0, $M_t$ = mass of litter at time t, t = time of incubation (usually in days, months or years), k = decomposition rate constant.

To calculate the decomposition rate, regress the natural log (ln) of percentage of DM remaining (y-axis) on days of exposure (x-axis) using the DM of the handling-loss leaf packs as 100% remaining for day 0. The negative slope of the regression line is equal to the processing coefficient (k) and therefore the $R^2$ values were displayed for the entire sampling time (30 days)

**Data analysis**

A 3-way ANOVA was used to analyze the data collected. The analysis was done using STATISTICA software program 2010. Fisher's least significant difference was used to compare treatment means at 5% level of probability.

**RESULTS**

Table 1: **Soil characteristics determined in the screen house before and after placement/ incorporation of legume residues in soil surface and buried sub soil collected from two seasons.**

| Parameters | Initial soil nutrients content | Season 1 | | Season 2 | |
|---|---|---|---|---|---|
| | | Soil surface | Sub soil | Soil surface | Sub soil |
| pH ($H_2O$) | 6.60 | 6.90 | 7.00 | 6.90 | 7.10 |
| Organic C (%) | 2.17 | 2.84 | 2.31 | 3.65 | 3.17 |
| Total N (%) | 0.16 | 0.39 | 0.21 | 0.41 | 0.32 |
| C/N ratio | 13.6 | 7.28 | 11.0 | 8.90 | 9.91 |
| Sand (%) | | 39.3 | 39.5 | 39.0 | 39.6 |
| Silt (%) | | 27.5 | 27.9 | 27.6 | 27.8 |
| Clay (%) | | 33.2 | 32.6 | 33.4 | 32.6 |

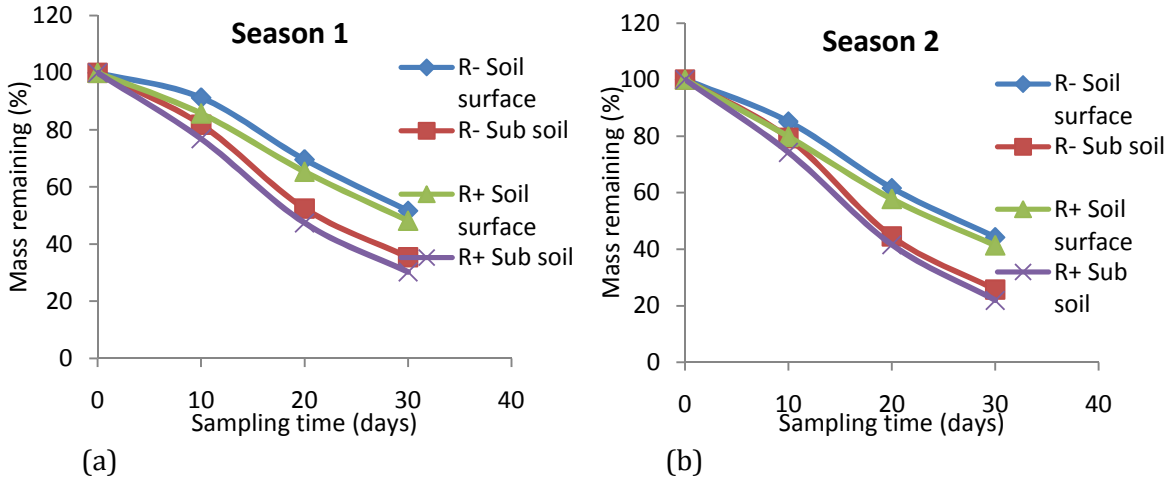
The screen house soil was lower in initial organic carbon and total nitrogen contents compared to when legumes crop residues collected from two seasons were incorporated as was rated as low to medium in terms of fertility [16]. The pH of the initial soil was 6.60 but increased with residues additions collected from season 1 and 2 (Table 1). The soil textural class of the screen house soil was clay loam according to Landon [16].

Averaged over placement methods, sampling days, *Rhizobium* inoculation, residue types, cropping systems and mass loss of legume residues were significantly ($p \leq 0.001$; $p \leq 0.01$; $p \leq 0.05$) different among the litter residues collected from two seasons (Fig. 1a-b, 2a-b and 3a-b).

Therefore, the mass loss due to *Rhizobium* inoculation were by 6 % to 6.1 % for 10 sampling days, 6.1 % to 9.6 % for 20 sampling days and 6.7 % to 14.6 % for 30 sampling days for surface and buried litter residues respectively for residues collected from season 1. For residues collected from season 2, the mass loss due to *Rhizobium* inoculation were by 6.2 % to 6.4 % for 10 sampling days, 6.2 % to 6.5 % for 20 sampling days and 6.4 % to 14.6 % for 30 sampling days for surface and buried litter residues respectively.

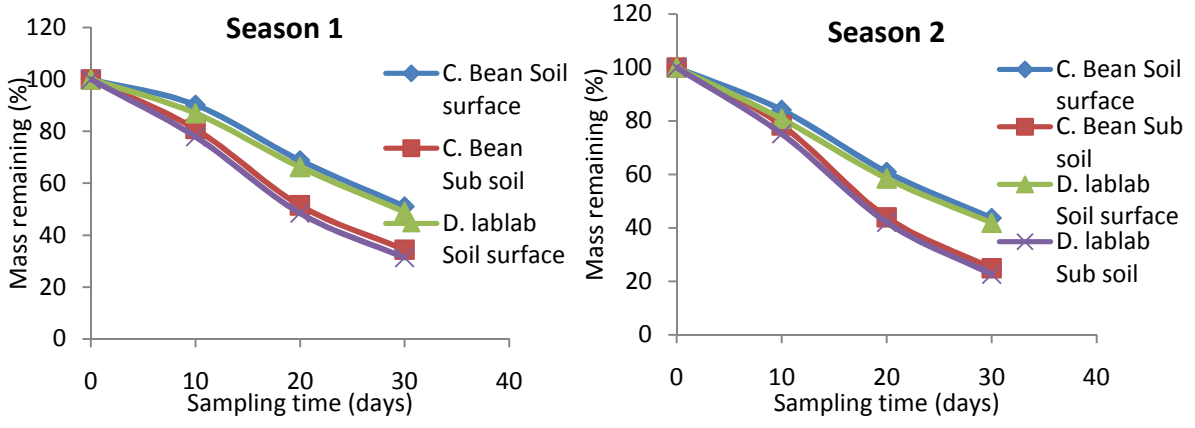
The mass loss due to legumes residue type were by 3.6 % to 3.7 % for 10 sampling days, 3.7 % to 5.8 % for 20 sampling days and 4.1 % to 9 % for 30 sampling days for surface and buried litter residues respectively for residues collected from season 1. For residues collected from season 2, the mass loss due to legumes residue type were by 3.9 % to 4.1 % for 10 sampling days, 3.9 % to 4.3 % for 20 sampling days and 4 % to 9 % for 30 sampling days for surface and buried litter residues respectively.

The mass loss due to cropping systems were by 4.2 % to 4.2 % for 10 sampling days, 4.6 % to 6.8 % for 20 sampling days and 5.2 % to 8.9 % for 30 sampling days for surface and buried litter residues respectively for residues collected from season 1. For residues collected from season 2, the mass loss due to cropping systems were by 4.1 % to 4 % for 10 sampling days, 4.1 % to 3.8 % for 20 sampling days and 4 % to 10.5 % for 30 sampling days for surface and buried litter residues respectively. The $R^2$ values for regressions ranged from 0.96 to 0.99 for the entire sampling period of 30 days regardless the experimental treatments used for the screen house experiment.



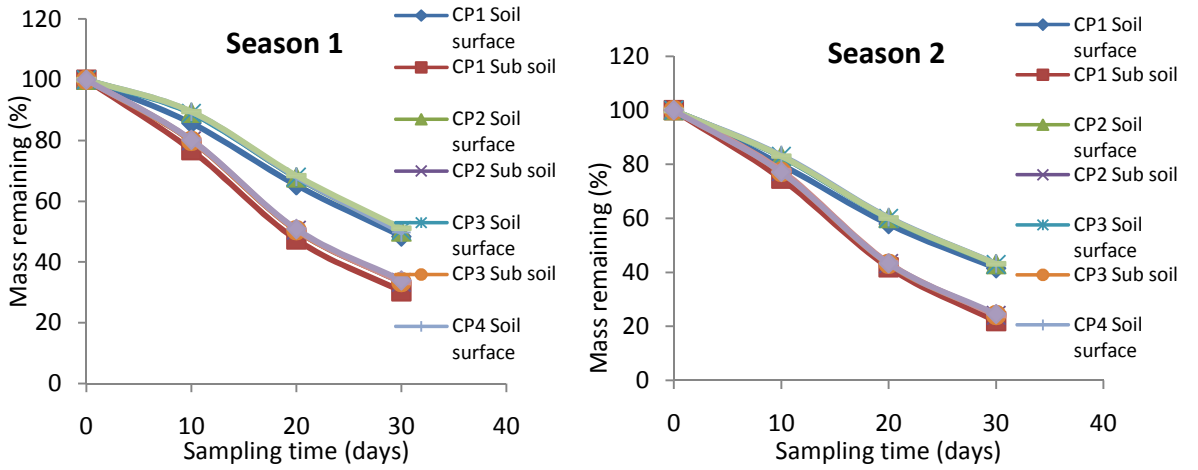

(a) (b)

Figure 1(a-b): Mass remaining of surface placed and subsoil-buried legume residues collected from cropping season 1 and 2 as affected by *Rhizobium* inoculation. (R-; without *Rhizobium*; R+; with *Rhizobium*)




(a) (b)

Figure 2(a-b): Mass remaining of surface placed and subsoil-buried legume residues collected from cropping season 1 and 2 as affected by two legumes. (C. Bean- Common bean; D. lablab- Dolichos lablab)




(a) (b)

Figure 3(a-b): Mass remaining of surface placed and subsoil-buried legume residues collected from cropping season 1 and 2 as affected by cropping systems. (CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

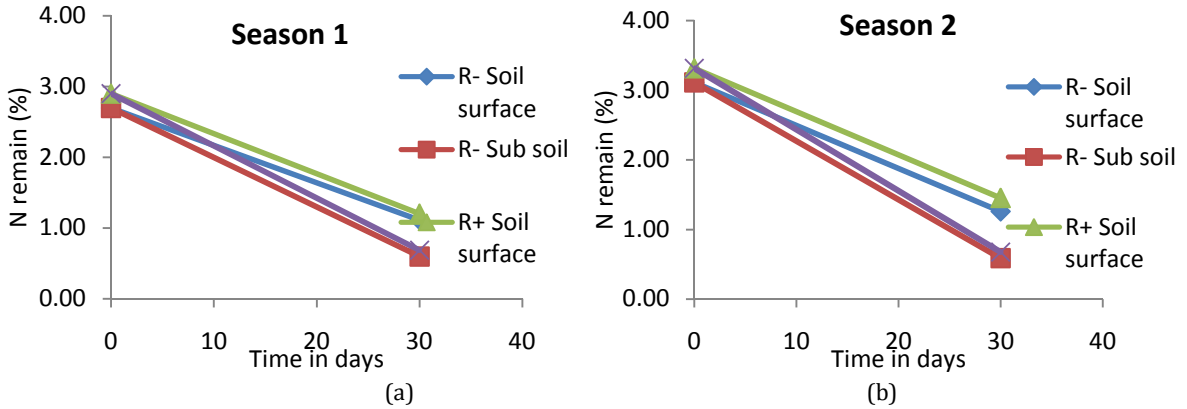
The initial N concentration of the litter residues were influenced by *Rhizobium* inoculation, legume types and cropping systems for both cropping seasons (Table 2). The N concentration changed from 6.9 % to 6.3%, C concentration changed from 12.8 % to 13.3 % whiles the C: N ratio changed from 6.4 % to 7.7 % for season 1 and 2, respectively due to *Rhizobium* inoculation. The legume types affected the N concentration by 7.9 % and 6.9 %, C concentration was affected by 14 % to 14.5 % while the C: N ratio was affected by 7.1 % to 8.2 % for season 1 and 2, respectively. The cropping systems affected the N concentration by 7.5 % and 3.5 %, C concentration was affected by 15.7 % to 11.3 % while the C: N ratio was affected by 9.4 % to 6.1 % for season 1 and 2, respectively.

**Table 2**: Effects of *Rhizobium* inoculation and intercropping systems on initial nitrogen and carbon concentration, initial carbon to nitrogen ratio and nitrogen remaining after 30 days incubation both on the surface and sub soil of two legumes (*P. vulgairis and D. lablab*) residues collected from two cropping seasons

| Treatments | Season 1 (% N remaining) | | | | | Season 2 (% N remaining) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Initial residual nutrients | | | Soil surface (time in days) | Sub soil (time in days) | Initial residual nutrients | | | Soil surface (time in days) | Sub soil (time in days) |
| | %N t=0 | %C | C:N | %N t=30 | %N t=30 | %N t=0 | %C | C:N | %N t=30 | %N t=30 |
| **Rhizobium** | | | | | | | | | | |
| R- | 2.69±0.03b | 43.09±1.01b | 15.93±0.23b | 1.11±0.02b | 0.60±0.01b | 3.11±0.03b | 42.08±0.92b | 13.48±0.19b | 1.26±0.03b | 0.59±0.01b |
| R+ | 2.89±0.03a | 49.43±0.91a | 17.02±0.21a | 1.20±0.02a | 0.69±0.01a | 3.32±0.03a | 48.53±0.95a | 14.60±0.20a | 1.45±0.03a | 0.68±0.01a |
| **Legumes** | | | | | | | | | | |
| 1 | 2.68±0.03b | 42.81±1.05b | 15.87±0.24b | 1.11±0.02b | 0.59±0.01b | 3.10±0.03b | 41.76±0.83 | 13.44±0.18b | 1.25±0.02b | 0.58±0.01b |
| 2 | 2.91±0.02a | 49.77±0.78a | 17.08±0.18a | 1.21±0.01a | 0.69±0.01a | 3.33±0.02a | 48.85±0.95 | 14.64±0.21a | 1.47±0.03a | 0.68±0.01a |
| **Intercropping systems** | | | | | | | | | | |
| 1 | 2.94±0.06a | 51.24±1.83a | 17.41±0.40a | 1.23±0.03a | 0.71±0.03a | 3.35±0.06a | 48.77±2.09a | 14.48±0.41a | 1.47±0.07a | 0.68±0.03a |
| 2 | 2.81±0.05b | 46.45±1.41b | 16.49±0.24b | 1.16±0.02b | 0.65±0.02b | 3.23±0.05b | 45.87±1.99b | 14.15±0.41a | 1.37±0.06b | 0.64±0.03b |
| 3 | 2.76±0.04b | 45.04±1.65b | 16.23±0.39b | 1.14±0.03b | 0.63±0.02b | 3.18±0.04b | 44.49±1.05b | 13.98±0.23a | 1.33±0.03b | 0.62±0.01bc |
| 4 | 2.72±0.05b | 43.17±2.06b | 15.77±0.48b | 1.11±0.03b | 0.60±0.03b | 3.14±0.05b | 44.11±1.15b | 14.02±0.22a | 1.32±0.03b | 0.61±0.02bc |
| 5 | 2.75±0.04b | 45.39±1.11b | 16.46±0.18b | 1.15±0.02b | 0.63±0.02b | 3.17±0.04b | 43.28±1.94b | 13.59±0.44a | 1.29±0.05b | 0.60±0.03c |
| **3-Way ANOVA (F-statistic)** | | | | | | | | | | |
| Rhiz | 405.7*** | 126.52*** | 37.99*** | 66.22*** | 126.52*** | 411.8*** | 97.10*** | 37.44*** | 93.81*** | 97.10*** |
| Leg | 503.8*** | 154.93*** | 47.06*** | 81.19*** | 154.93*** | 518.4*** | 117.16*** | 43.19*** | 117.96*** | 117.16*** |
| Cr syst | 54.4*** | 23.07*** | 9.27*** | 14.27*** | 23.07*** | 55.5*** | 8.64*** | 2.45ns | 9.07*** | 8.64*** |
| Rhiz*Leg | 12.1*** | 6.27** | 4.11** | 3.90ns | 6.27** | 11.9*** | 1.78ns | 1.29ns | 1.47ns | 1.78ns |
| Rhiz*Cr syst | 2.4ns | 1.97ns | 2.32ns | 2.12ns | 1.97ns | 2.4ns | 2.16ns | 1.93ns | 2.63** | 2.16ns |
| Leg* Cr syst | 2.3ns | 3.10** | 4.77** | 3.84** | 3.10** | 3.0** | 6.62*** | 6.47*** | 5.66*** | 6.62*** |
| Rhiz* Leg*Cr Syst | 1.7ns | 6.56*** | 5.62*** | 6.15*** | 6.56*** | 2.0ns | 1.75*** | 2.31ns | 1.49ns | 1.75ns |

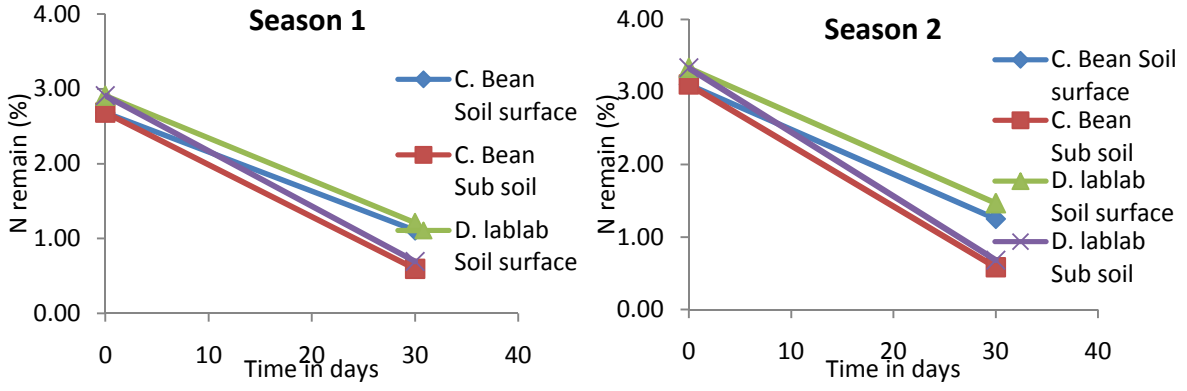
R-: Without Rhizobium, R+; With Rhizoubium, Legume 1: Common bean; Legume 2: D. Lablab; Intercropping System 1, 2, 3, 4 and 5 are sole maize, 10cm, 20 cm, 45cm and 0 cm of legumes from maize row respectively; Rhiz; Rhizobium, Leg; Legume, Cr Syst; Intercropping Systems. Values presented are means ± SE, n=4. **; *** = significant at P≤0.01, P≤0.001 respectively, ns = not significant, SE = standard error. Means followed by dissimilar letter in a column are significantly different from each other at P=0.05 according to Fischer least significance difference (LSD)

Nitrogen release from the decomposing leaf litter varied greatly between above and below soil samples placement (Table 2). The results indicated that the N release was maximum at sub soil during first 30 days as compared to the surface soil. The amount of N remained in the soil surface and sub soil after 30 days decomposition changed with *Rhizobium* inoculation, legumes type and cropping systems. The *Rhizobium* inoculation affected the N release after 30 days by 7.5 % and 13.1 % for surface soil and 13 % and 13.2 % for sub soil residues for residues collected from season 1 and 2 respectively. The legumes type affected the N release after 30 days by 8.3 % and 14.9 % for surface soil and 14.5 % and 14.7 % for sub soil for residues collected from season 1 and 2 respectively. The cropping systems affected the N release after 30 days by 9.8 % and 10.2 % for surface soil and 15.5 % and 11.8 % for sub soil for residues collected from season 1 and 2 respectively. The $R^2$ value for % N remaining was 1 for all treatments for residues collected from two cropping seasons.



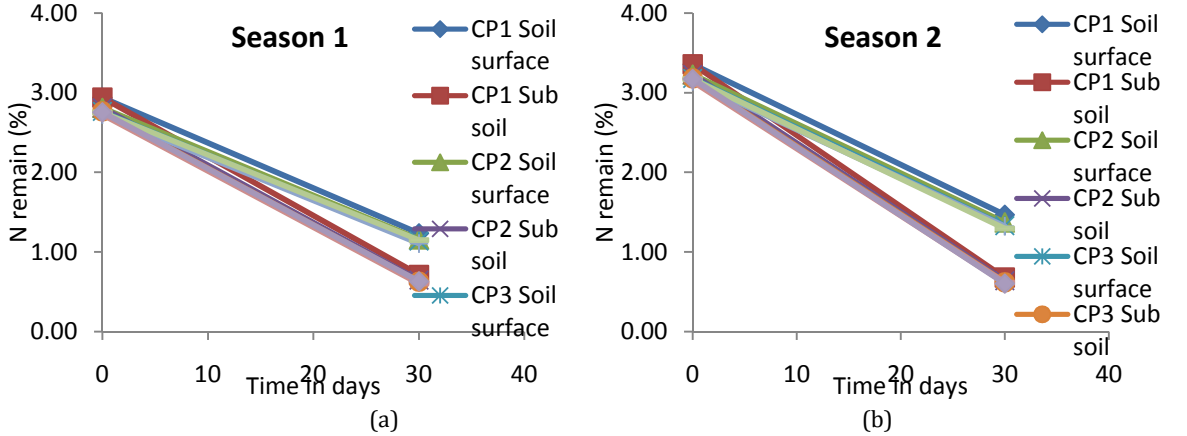

(a) (b)

Figure 4(a-b): **Nitrogen remaining of surface placed and subsoil-buried legume residues collected from cropping season 1 and 2 as affected by *Rhizobium* inoculation. (R-; without *Rhizobium*; R+; with *Rhizobium*)**




(a) (b)

Figure 5(a-b): **Nitrogen remaining of surface placed and subsoil-buried legume residues collected from cropping season 1 and 2 as affected by two legumes. (C. Bean- Common bean; D. lablab- Dolichos lablab)**




(a) (b)

Figure 6(a-b): **Nitrogen remaining of surface placed and subsoil-buried legume residues collected from cropping season 1 and 2 as affected by cropping systems. (CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)**

The current study reported significant interactive effects between *Rhizobium* inoculation and legumes on initial N content for season 1 and 2 (fig. 7), initial C content for season 1 (fig. 9), C: N ratio for season 1 (fig. 12) and sub soil N remain for season 1 (fig. 18). Interaction between *Rhizobium* and cropping systems had significant effect on surface N remains for season 2 (fig. 15). Interaction between legumes and cropping systems had significant effect on initial N content for season 2 (fig. 8), initial C content for season 1 and 2 (fig. 10), C: N ratios for season 1 and 2 (fig. 13), surface N remains for season 1 and 2 (fig.16), sub soil N remains for season 1 and 2 (fig. 19). Interactive effects of *Rhizobium*, legumes and cropping systems were significant on initial C content in for season 1 and 2 (fig. 11), C: N ratios for season 1 (fig. 14), surface soil N remains for season 1 (fig. 17) and sub soil N remains for season 1 (fig.20).

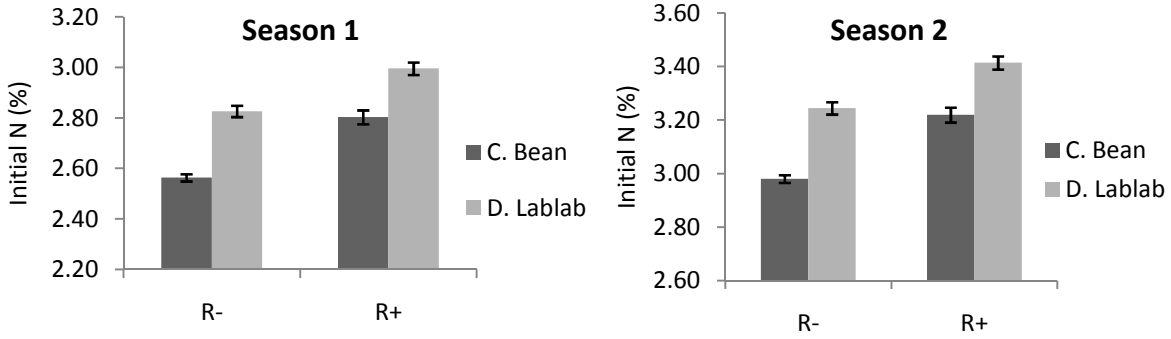



Figure 7: Interactive effects of *Rhizobium* and legumes on initial N content in litter residues collected from season 1 and 2: (R-: Without *Rhizobium*, R+: With *Rhizobium*, C. bean: *P. vulgaris*, D. lablab: *D. lablab*)

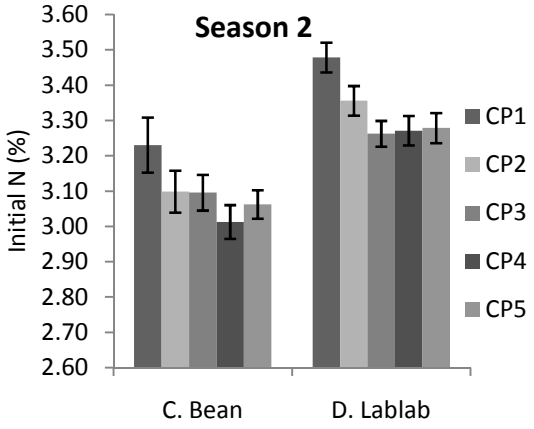



Figure 8: Interactive effects of legumes and cropping systems on initial N content in litter residues collected from season 1 and 2: (C. bean: *P. vulgaris*, D. lablab: *D. lablab*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

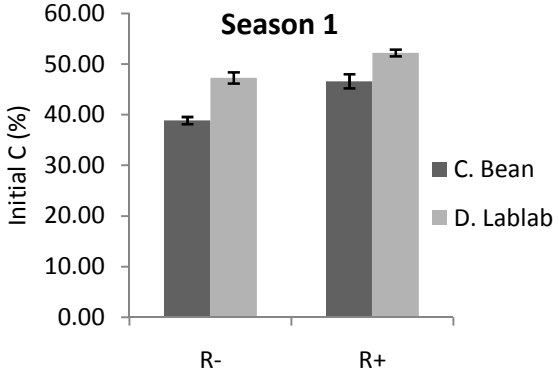



Figure 9: Interactive effects of *Rhizobium* and legumes on initial C content in litter residues collected from season 1: (R-: Without *Rhizobium*, R+: With *Rhizobium*, C. bean: *P. vulgaris*, D. lablab: *D. lablab*)

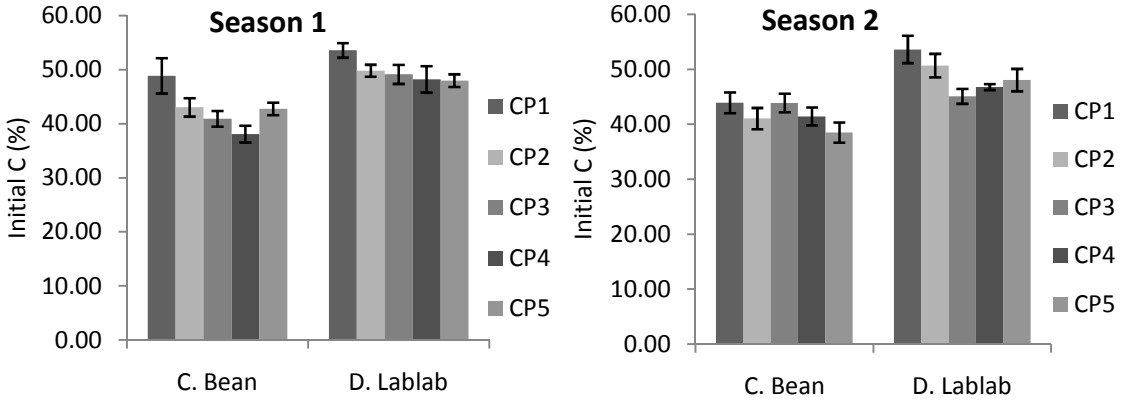



Figure 10: Interactive effects of legumes and cropping systems on initial C content in litter residues collected from season 1 and 2: (C. bean: *P. vulgaris*, D. lablab: *D. lablab*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

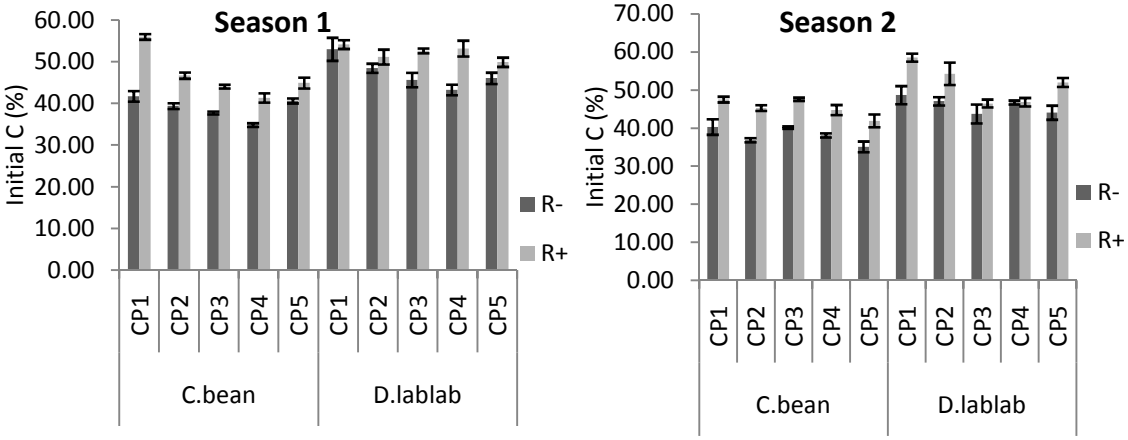



Figure 11: Interactive effects of *Rhizobium*, Legumes and cropping systems on initial C content in litter residues collected from season 1 and 2: (R-: Without *Rhizobium*, R+: With *Rhizobium*, C. bean: *P. vulgaris*, D. lablab: *D. lablab*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

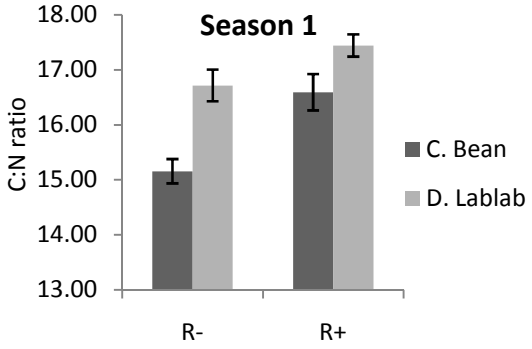



Figure 12: Interactive effects of *Rhizobium* and legumes on initial C:N ratio content in litter residues collected from season 1: (R-: Without *Rhizobium*, R+: With *Rhizobium*, C. bean: *P. vulgaris*, D. lablab: *D. lablab*)

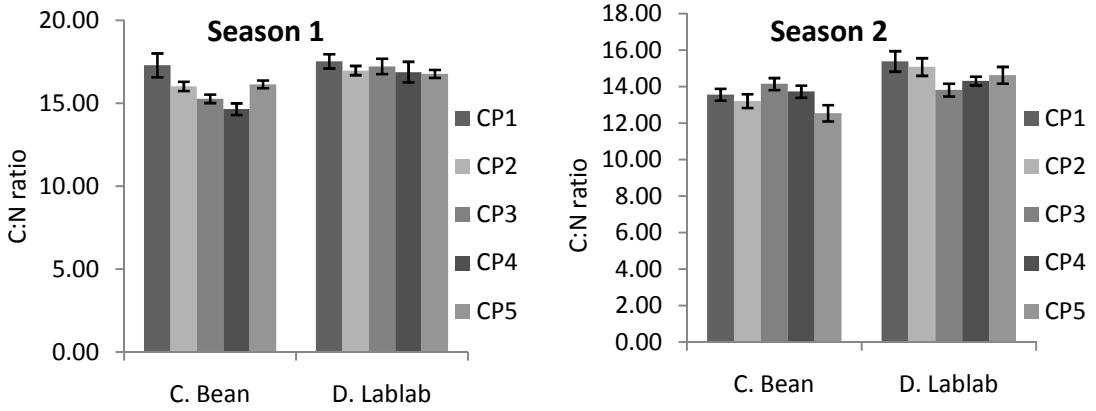



Figure 13: Interactive effects of legumes and cropping systems on C:N ratio content in litter residues collected from season 1 and 2: (C. bean: *P. vulgaris*, D. lablab: *D. lablab*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

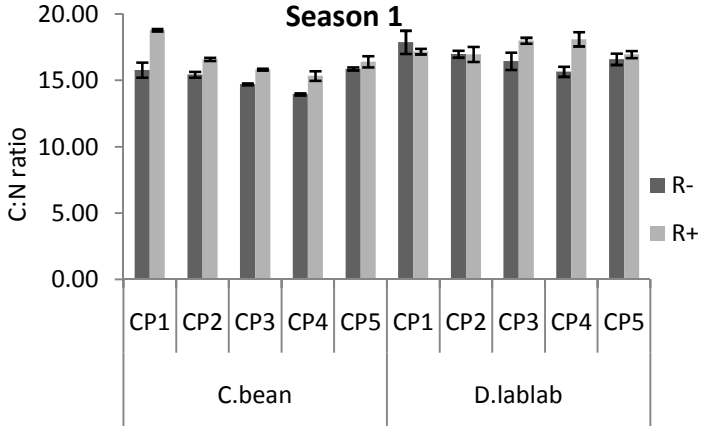



Figure 14: Interactive effects of *Rhizobium*, Legumes and cropping systems on C:N ratio content in litter residues collected from season 1: (R-: Without *Rhizobium*, R+: With *Rhizobium*, C. bean: *P. vulgaris*, D. lablab: *D. lablab,* CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

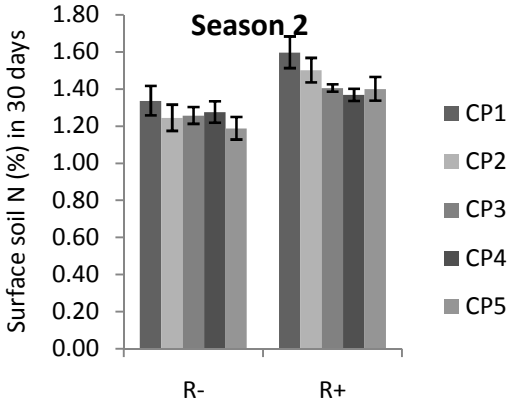



Figure 15: Interactive effects of *Rhizobium* and cropping systems on surface soil N remain after 30 days collected from season 2: (R-: Without *Rhizobium*, R+: With *Rhizobium*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

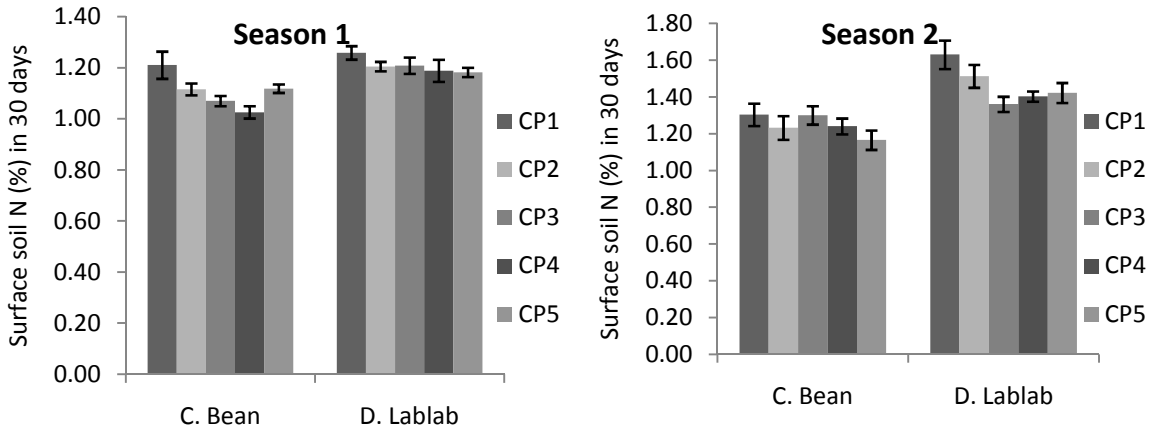



Figure 16: Interactive effects of legumes and cropping systems on surface soil N remain after 30 days collected from season 2: (C. bean: *P. vulgaris*, D. lablab: *D. lablab*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

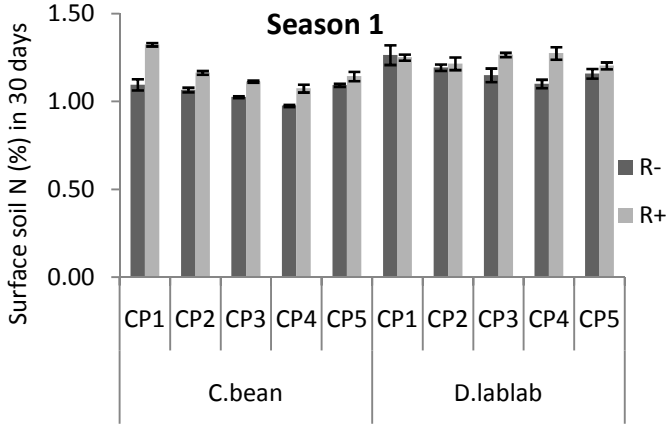



Figure 17: Interactive effects of *Rhizobium*, Legumes and cropping systems on surface soil N remain after 30 days collected from season 1: (R-: Without *Rhizobium*, R+: With *Rhizobium*, C. bean: *P. vulgaris*, D. lablab: *D. lablab*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

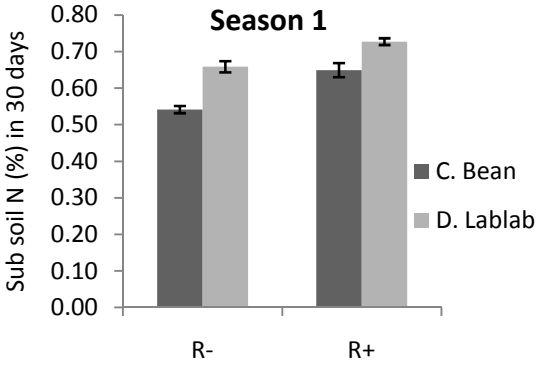



Figure 18: Interactive effects of *Rhizobium* and legumes on sub soil N remain after 30 days collected from season 1: (R-: Without *Rhizobium*, R+: With *Rhizobium*, C. bean: *P. vulgaris*, D. lablab: *D. lablab*)

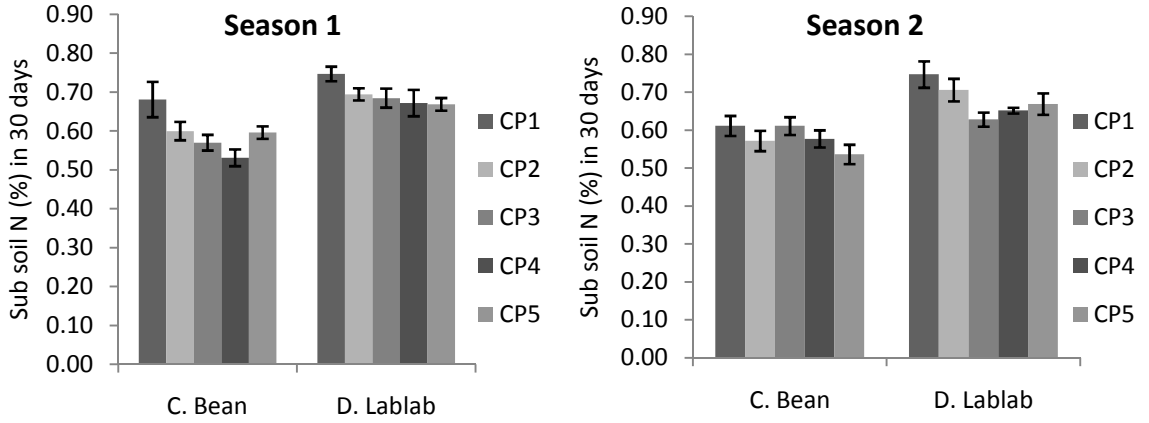



Figure 19: Interactive effects of legumes and cropping systems on sub soil N remain after 30 days collected from season 1 and 2: (C. bean: *P. vulgaris*, D. lablab: *D. lablab*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

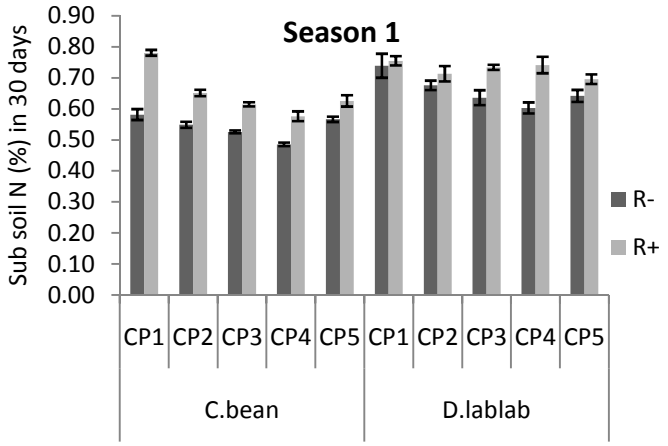



Figure 20: Interactive effects of *Rhizobium*, Legumes and cropping systems on sub soil N remain after 30 days collected from season 1: (R-: Without *Rhizobium*, R+: With *Rhizobium*, C. bean: *P. vulgaris*, D. lablab: *D. lablab*, CP1: Cropping system 1, CP2: Cropping system 2, CP3: Cropping system 3, CP4: Cropping system 4, CP5: Cropping system 5)

**DISCUSSION**

The sub-soil pH was higher than surface soil pH after incorporation of residues from both cropping seasons although both were in the neutral soil pH ranges. Anderson and Ingram [17] postulated that soil pH tends decrease with soil depth but in the current study the soil depth (10cm) and residues were not significant enough to influence the changes in soil pH. The surface and sub soil pH provide information for soil nutrients such as P, K, Ca, Mg, Na and Zn that enable nutrient management decisions. The soil textural class of surface and sub soil did not differ much in both seasons of residues incorporation. This gives the clue that the physical properties of the soils do not change due to addition of organic matter/ crop residues. The surface placed soils residues had more carbon and nitrogen content compared to buried soil residues. This has been attributed to the fact that in the surface residue, there is less microorganisms and insufficient soil moisture that would promote the decomposition rate of residues as opposed to buried soil crop residues. The carbon to nitrogen ratio was higher in the analysis of initial soil before incorporation of crop residues followed by buried residues carbon to nitrogen ratio and finally the surface soil carbon to nitrogen ratio. These determined the litter quality of the incorporated legumes crop residues implying that the lower the carbon to nitrogen ratio the higher the decomposition rate of the materials while the higher the carbon to nitrogen ratio the lower the decomposition rates of the crop residues incorporated.

The mass loss during the first 10 days of sampling for both surface and buried crop residues followed the same trend of persisted and thereafter increased rapidly during the subsequent sampling periods of 20 and 30 days of sampling for both surface and buried crop residues in both seasons. As compared to

season 1, residue mass loss was significantly greater in season 2 across the sampling days but in both cropping seasons the buried samples loss more mass than surface placement residues. The higher mass loss was due to high decomposition rates of residues collected from season 2 that could be attributed to higher microbial activity due to more favourable microclimate, mainly soil moisture for the buried residues. Also the more nutrients content in crops residues incorporated in season 2 influenced the decomposition rates as determined by initial carbon to nitrogen ratio of the residues. This is due to the fact that in the early phase of decomposition, the presence of high concentrations of nutrients such as carbon and nitrogen in residues may exert a rate enhancing influence on mass loss of the litter that is not lignified but in the late stage, where mainly lignified material remains. The degradation of litter is ruled by lignin mass loss, which is negatively affected by high nitrogen concentrations and positively affected by high concentrations of celluloses in the lignified material [11].

In general, the pattern of mass loss was similar for surface applied and subsoil-buried residues across sampling days during the study period. A study by Abera et al. [2] indicated that, the mass loss was faster in buried than surface-placed litterbags and observed the overall residue mass loss of 43 % of surface applied lower than subsoil-buried residue of leguminous crops. Further studies by Miki et al. [18]; Hoorens et al. [12] as cited by Abera et al. [2] outlined the reasons for the faster residue mass loss for buried than surface-placed litterbags as probably related to moisture content (surface placed litterbags dry up easily on warm days, despite some moisture in the soil), although factors such as biomass-soil contact, availability of mineral nitrogen and other elements to the decomposer communities may have been of importance. The primary controlling factor of surface litter mass loss is soil moisture and therefore, burying/incorporation of residues may not always be necessarily important; as for example, there was slight difference in residue decomposition between surfaces applied and buried residues. The mass remaining followed a first-order decay function because the mass put in a litterbag exponentially declined over sampling period as described by exponential decay curves of ($R^2$=0.96-0.99) for the entire decomposition experiment period (0–30 days) for the two cropping seasons. Similarly, Zhang et al. [19] reported that a first-order exponential decay function can be used to adequately describe litter decomposition process in the majority of cases.

The results suggest that N loss between decomposing leaf residues with different N status in legume residues significantly influence decomposition process and N release. The rate of N release followed the same trend as mass loss. Litter buried in the soil lost more N than litter on the soil surface after 30 days. The initial concentrations of N and C, and the ratios of C: N, are generally recognized as the main litter quality variables controlling rates of decomposition and N release [20]. For example, the net N release after 30 days of litters with initial C: N ratios lower than 52, was 50 % higher than litter with C: N ratios lower than 20 and therefore the litter net N release rate was negatively related to initial C: N ratio when buried in the soil than when is in the soil surface. When litter residues were place on the surface soil (from field observation of this study) indicated that macro-invertebrates move deeper in the soil and therefore due to this difference between dry and wet in surface and sub soil an inhibition of decomposer community results in a transient accumulation of litter on the soil surface with less loss of N. A study by Manzoni et al. [21] reported that the decomposers use the organic C in the litter as their primary energy source which results to respiration and the amount of C in the litter continuously to decreases but the N increased in the decomposer tissues and therefore the dynamics of N may not follow the same pattern as the dynamics of C. In this case the C: N ratio varies because of differences in N content of litter residues and not C content. Furthermore, Manzoni et al. [21] indicated that the nitrogen loss due to excess nitrogen in a low C: N ratio can be over 60% and at a C: N ratio of 30 or 35 to 1, only one half of one percent of the nitrogen will be lost but in our study indicated C: N ratios higher than 30:1 and therefore there will be N loss with time during decomposition.

The initial release or decline of N concentration can be due to leaching of the soluble form of N, while the second phase can be due to binding of N to lignin and polyphenols in the tissues and as this process continues mineralization results in to the decline of N in litter and this account for N release [2]. The C: N ratios of the tested legumes in this study indicated high quality litters with higher N concentrations which led to the rapid N mineralisation and higher decomposition rate. Since the litter residues C: N ratio is less than 20, the decomposition and N mineralisation is expected to be rapidly.

## CONCLUSION

The 30 days screen house experiment showed that residue quality had influence on litter residue decomposition rates. Due to differences in legumes initial N and C concentrations and low C: N ratio, *D. lablab* residues decomposed faster than *P. vulgaris* residues as influenced by *Rhizobium* inoculation and cropping systems. The high quality legumes such as *D. lablab* residues have the potential to promote

nutrient cycling in agricultural systems. This rapid decomposition and N release from legume residue can result in to the increased production of the subsequent crops. Also this study highlights the complex interaction between cropping systems and inoculated legumes and warrant further study about the interactive effects between legumes litter and other crop residues on decomposition.

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