



# Decomposition of Litter and Nutrient Release Dynamics Associated with NPK Fertilizer Rate of Tomato (*Lycopersicon lycopersicon* L.) Cultivation

<sup>1</sup>Isah, A. S., <sup>1</sup>Ahmed, A. and <sup>2</sup>Abubakar, H.

<sup>1</sup>Department of Agronomy, <sup>2</sup>Department of Plant Science,  
Faculty of Agriculture/Institute for Agricultural Research, Ahmadu Bello University, Zaria  
[shero4me@gmail.com](mailto:shero4me@gmail.com)

## ARTICLE INFO

### History:

Received: 1<sup>st</sup> July, 2020

Accepted: 1<sup>st</sup> August, 2021

Received in revised form:  
10<sup>th</sup> August, 2021

Published: 28<sup>th</sup> September, 2021

### Keywords

Decomposition rate, Green manure legumes, Incubation, NPK fertilizer, Nutrient release.

## ABSTRACT

A field incubation experiment was conducted for 70 days to determine decomposition rate and nutrient dynamics of N, P & K release by green manure legume Lablab (*Lablab purpureus*) in NPK fertilizer rate application of Tomato (*Lycopersicon lycopersicon* L.) at Kadawa, Northern Guinea Savanna in Nigeria. The treatments are plots of inorganic fertilizer of (0, 150, 300 and 450 kg ha<sup>-1</sup>) where the decomposition study was monitored. The experiment was carried out under field conditions in Randomized Complete Block Design with four replications. Decomposition was monitored by harvesting the litter bags and analyzing the residues at stated intervals of 0, 3, 7, 14, 21, 28, 56 and 70 days from the time green manure was incorporated. The nutrient release was evaluated at 28 days after incorporation of litter bags. The litter decomposition and nutrient release concentrations were assessed. The result showed that higher decomposition rate and nutrient release was obtained from higher rate of NPK fertilizer rate. From this study it also revealed that it took 11 days after incorporation of Lablab green manure released 50% of total mass has been decomposed. Hence, the green manure has the potential to decay rapidly and release nutrients for vegetable production.

© 2021 TAJET All rights reserved

## Introduction

Nigeria is one of the developing countries the world where agriculture hold one of the major economy activity and majority of the farmers are smallholders located in soils of inherent low fertility combined with no fallow or lack of adequate fertilization of inputs that results to depletion of nutrients reserves for vegetable production. Green manure has received renewed attention with emphasis on long term sustainability of agricultural system because it can be used as a source of soil nutrients and alternative to maintenance of soil fertility [1, 2]. Research have shown that the use of green manure crops for soil fertility restoration is among the most promising technologies to overturn the soil degradation problems for the rural poor [3]. Herbaceous legumes (*Lablab purpureus*) offer a low cost opportunity for maintaining soil fertility by contributing nutrients during decomposition as much as 200 kg N ha<sup>-1</sup>, 30 kg P ha<sup>-1</sup> and 60 kg K ha<sup>-1</sup> [4, 5] which is an assured means of improving crop yields, quality and at same time improving soil fertility status in an economic and environmentally friendly.

Organic matter has been shown to be critical for improving soil quality and optimizing nutrient and water efficiencies and ultimately crop productivity in such degraded soils [6-9]. Legumes are thought to be superior to non-legume green manure crops because they show an exceptional ability to utilize rather inaccessible soil phosphorus (P) and potassium (K) fractions [10], hence improving availability of P and K to subsequent crops.

Decomposition and mineralization studies conducted by [11] showed that N is released rapidly from green manure during the first 2-3 weeks after incorporation and then slows down. About 40 -50% of legumes residues can decompose in a month [12], while Prescott [13], reported that it takes about three to six weeks for organic matter to adequately decompose in the tropics further more air-drying depresses rate of leaf decomposition. Immature plant material usually decomposes faster than mature material [14]. Decomposition requires adequate moisture to proceed but excess water interferes with oxygen to decomposition facilitating microbes and causes major changes in the medium (soil), the nature and product of the process [15]. Moro and Domingo [16] reported that decomposition is not fully complete and slower under anaerobic condition than under aerobic conditions. Blair *et al.* [17] reported that it is likely that acidity slows down decomposition by restricting the activities of the soil microbial population to relatively small number of species. The amount of nutrient recycled in a soil system depend on the quality and quantity of the soil biomass but the rate of decomposition and nutrient release of the biomass is however, determined by its chemical composition and climatic conditions [18].

The study and understanding the decomposition rate and nutrient release patterns of green manure legume residues is crucial in uptake by crops. Green Manure decomposition rate and subsequent nutrient release depend largely on residue quality and

quantity, soil moisture and temperature and specific soil factors such as texture, mineralogy and acidity, biological activity and the presence of other nutrients [19]. Studies on litter mineralization have linked rate of nutrient release to biochemical properties, especially lignin, polyphenols and N content [20-22]. Despite the significance of green manure in ameliorating soils, the use of green manure has not received the desired attention amongst smallholder farmers of tomato production. However, no effort has been made to study and evaluate litter decomposition and nutrient release of lablab green manure under inorganic NPK fertilizer application. Therefore, objectives of this study is to determine the decomposition rate, days to 50% decomposition and nutrient release patterns of green manure legume Lablab (*Lablab purpureus*) under varying NPK fertilizer rate of tomato.

**Materials and Methods**

*Experiment site*

The study was conducted at the Institute for Agricultural Research, Irrigation Research Station Kadawa (11°39' N, 08°02'E 500 m above sea level) in the Sudan savanna agro-ecological zone of Nigeria. The soil was characterized as sandy loam and slightly acidic ranging from 6.0 to 6.4, organic carbon 0.73 to 2.03 g kg<sup>-1</sup>, total nitrogen 0.30 to 0.53 g kg<sup>-1</sup>, available phosphorus 12.3 to 25.3 g kg<sup>-1</sup>, potassium ranges between 0.08 to 0.14 cmol kg<sup>-1</sup> while the exchangeable bases were 1.70 to 1.90 cmol kg<sup>-1</sup> Ca, 1.25 to 1.30 cmol kg<sup>-1</sup> Mg, 0.08 to 0.14 cmol kg<sup>-1</sup> Na, 0.09 to 0.16 cmol kg<sup>-1</sup> H + Al and CEC of 7.20 to 9.60 cmol kg<sup>-1</sup> of soil.

*Treatments and Experimental Design*

The treatments consisted of four (4) NPK fertilizer rate (0, 150, 300 and 450 kg ha<sup>-1</sup>) plots where decomposition studies were monitored and the plot size was measured 2m x 2m. The treatment was laid in a randomized complete block design, replicated four times.

*Decomposition Study of Fodder*

Fresh leaves and stems of lablab were harvested at 7 weeks after sowing, chopped and weighed into 50 g per sample and put into litter bags in plot size of 2m x 2m. The bags were measured 20 cm x 20 cm in 2 mm nylon mesh bags and buried 10 cm depth into plots of inorganic fertilizer of (0, 150, 300 and 450 kg ha<sup>-1</sup>). Decomposition was monitored by harvesting the litter bags and analyzing the residues at stated intervals of 0, 3, 7, 14, 21, 28, 56 and 70 days from when green manure was introduced. At each sampling period, litter bags were removed weighted as initial weight and oven dried to constant weight for 24 hrs. The initial weight and over dried weight were used to calculate the following parameters.

(a) Mass loss percentage (%) is the rate of litter loss to the soil and it was expressed in percentage using the formula described by [23].

$$\begin{aligned} \text{Mass loss at } 105^{\circ}\text{C} (\%) &= \frac{\text{Initial Mass (g)} - \text{Final mass (g)}}{\text{Initial Mass (g)}} \\ &\times 100\% \end{aligned} \quad (1)$$

where initial mass is the weight at sampling time and final weight after oven dry at sampling time.

(b) Average Mass Remaining is computed using equation 2.

$$\begin{aligned} \text{Average Remaining Mass} &= \frac{\text{Final weight (g)}}{\text{Initial weight (g)}} \times 100\% \end{aligned} \quad (2)$$

(c) Decomposition rate percent per day is computed using equation 3.

$$\begin{aligned} \text{Decomposition Rate \% per day} &= \frac{\% \text{ Mass loss (105}^{\circ}\text{C)}}{\text{length of incubation (days)}} \end{aligned} \quad (3)$$

(d) Decay Constant (*k*). The decomposition of the plant material was monitored following the simple exponential decay model developed by [23], based on field and laboratory evidence of decomposition rates:

$$\text{Decay curve} = \ln\left(\frac{M_0}{M_t}\right) = kt \quad (4)$$

Where *M*<sub>0</sub> = Mass weight of litter at Zero time (0), *M*<sub>*t*</sub> = Mass weight of litter at sampling time *t*, *t* = Time of incubation in days, *k* = Decomposition constant or exponential decay coefficient.

(e) The half-life is a parameter used to facilitate the interpretation of plant residue decomposition data, which measures the period of time (*t*) required to decompose 50% of the material as shown below in equation 5.

$$\text{Half - life, } T_{50} = \frac{0.693}{k} \quad (5)$$

where *k* = decomposition constant. 0.693 is correction factor for converting *K*<sub>e</sub> to 1/2.

The nutrient release from the decomposing leaf litter of green manure was derived using the equation 6 [24].

$$\text{Nutrient release (\%)} = \frac{C_i \times M_i - C_t \times M_t}{C_i \times M_t} \quad (6)$$

where *C*<sub>*i*</sub> is the initial concentration of nutrients (N, P and K) and *C*<sub>*t*</sub> is the concentration of nutrients (N, P and K) in the decomposing litter at sampling time *t*. *M*<sub>*i*</sub> is the initial dry weight of the litter and *M*<sub>*t*</sub> is the dry weight of the decomposed litter at sampling time *t*.

*Statistical Analysis*

The nutrients released concentrations (N, P and K) in leaf and stem litter of different NPK fertilizer rate at the end sampling time was analyzed as a randomized complete block using the General Linear Model (GLM) procedure of the Statistical Analysis Software (SAS Institute).

**Results and Discussion**

*Green Manure chemical composition.*

The chemical composition of lablab fodder as green manure is presented in Table 1. The green manure nutrient composition showed high amount of total nitrogen ranges between 34.2 to 37.3 g kg<sup>-1</sup> total phosphorus 5.5-6.1 g kg<sup>-1</sup> potassium 10.8-12.1 g kg<sup>-1</sup> while carbon was between 48.8-59.4%. However, the fodder analysis showed a narrowed C:N ratios between 13-19 and the dry matter accumulation was between 424.0-460.5 g kg<sup>-1</sup>.

Table 1: Chemical composition of Lablab green manure used during the experimental periods at Kadawa in 2014 and 2015

Chemical composition	2014	2015
Total Nitrogen (g kg <sup>-1</sup> )	34.2	37.3
Total Phosphorus (g kg <sup>-1</sup> )	6.0	5.8
Potassium (g kg <sup>-1</sup> )	11.4	13.0
Calcium (g kg <sup>-1</sup> )	11.1	12.1
Carbon (%)	56.9	59.4
C:N ratio	17	19
Dry matter (g kg <sup>-1</sup> )	458.4	424.0

*Field Decomposition Pattern*

(i) Mass loss (%)

Figures 1 and 2 present the percentage mass loss by decomposing green manure in 2014 and 2015. The weight loss of green manure was rapid from the litter bags during the first 14 days, with respect to NPK fertilizer application rate in order of 450, 300, 150 kg ha<sup>-1</sup> and the control plot throughout the incubation period at both years of study. The corresponding mass loss of green manure residue under NPK fertilizer after 10 days were 59.7, 45.9, 43.6, 31.3 and 56.2, 46.7, 36.5, 37.2% in 2014 and 2015 respectively. It might be attributed to availability mineral N that led to accelerated rate of litter decomposition. Although the representation of C/N dynamics below ground remains critical uncertainly, due to the seemingly contradictory role of N in microbial decomposition of organic matter. Aber and Melillo [25] observed that enhanced N availability accelerates the decomposition of senescent plant tissue. Research has showed that added phosphorus had no effect on decomposition and P release on from the residues [26].

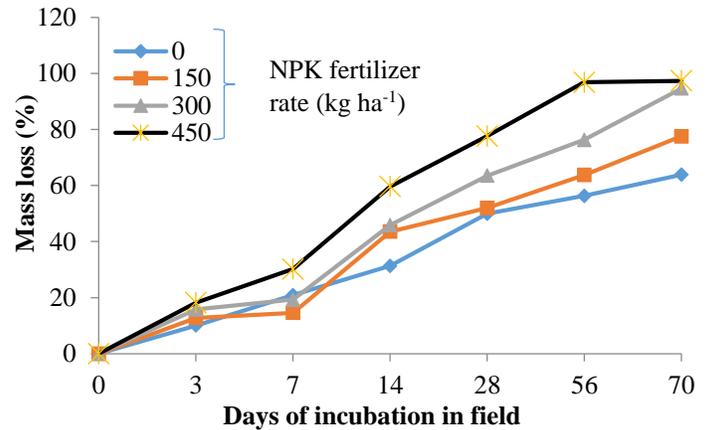


Fig. 1: Percent mass loss of green manure as influenced by different NPK fertilizer rate in 2014

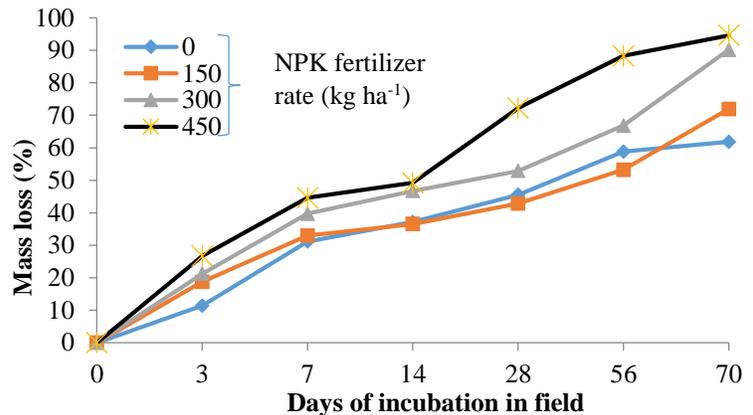


Fig. 2: Percent mass loss of green manure as influenced by different NPK fertilizer rate in 2015

(ii) Mass remaining (%)

The percent mass remaining of the green manure was more in the control plots than the plots treated with NPK fertilizer rates in a decreasing order as shown in Figures (3 and 4) in 2014 and 2015 respectively. At the end of 70 days decomposition study, mass remain of fodder from 0, 150, 300 and 450 kg ha<sup>-1</sup> NPK plots were 36.0, 22.6, 5.8, 3 and 38.1, 28.0, 10.0, 5.8% was yet to decomposed in the soil. Low mass remaining could be attributed to stage at which the green manure legume was incorporated into soil was tender and fibrous lignin were not developed. This finding is in contrast that addition of inorganic N to soil broadly show a suppression of microbial activity, which is inconsistent with N limitation of decomposition. Plant litter immobilizes N during initial stages of decay process [27] and litter with greater N content (lower C:N) decomposes more quickly [28].

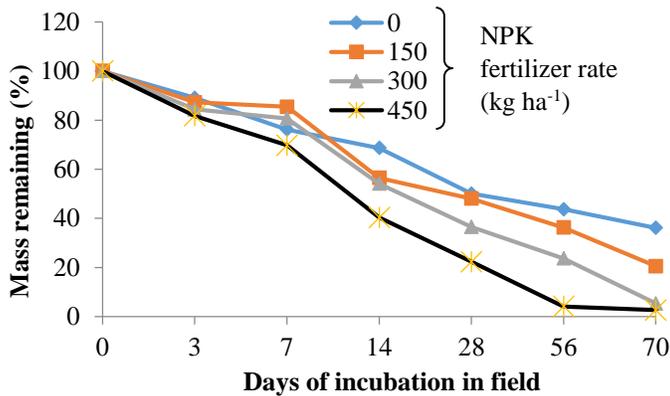


Fig. 3: Percent mass remaining of green manure as influenced by different NPK fertilizer rate in 2014

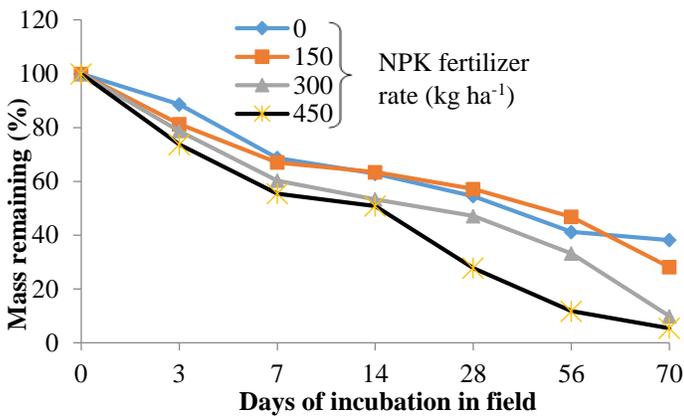


Fig. 4: Percent mass remaining of green manure as influenced by different NPK fertilizer rate in 2015

*Decomposition rate (day<sup>-1</sup>), Decay constant and days to 50% decomposition*

Table 2 present decomposition rate, decay constant and days to 50% decomposition. The decomposition rate was higher at the highest fertilizer rate (450 kg ha<sup>-1</sup>) and least at the control at both years. The rate increase with increase fertilizer application and this could be availability of nutrients for microbial activity from applied fertilizer and subsequent release of nutrient by adding carbon and nutrient availability for plant utilization. A high N content and low carbon content in leaves increases organic matter decomposability. Nitrogen and phosphorus are important source of energy for soil microorganisms [29]. Similar finding was observed by [30] who revealed that increases in the rate of decomposition can have additive impact on carbon cycle, increased nutrient availability and

release of CO<sub>2</sub> to atmosphere. Leaf litter source quality and C/N/P stoichiometry influence soil microbial activity and strongly affect the decomposition rate [29, 31].

The decay constant was also highest at the fertilizer rate of 450 kg ha<sup>-1</sup> and least in the control while the numbers of days to 50% decomposition was higher at the control and least at the highest fertilizer rate (11 days) in both years of study (Table 2). The shorter half-life and higher decay *k* were found at 450 kg ha<sup>-1</sup> application ranges between (0.3 - 0.6). It may be attributed to the quality and nutrient availability for fast microbial activities on the litter in the soil and it varied as result of amount of fertilizer applied the *k* value may not be up 1.0, therefore the turnover will occur within a year or less six months. Alvarez *et al.* [32] reported that *k* value is often greater than 1.0 for tropical forest indicates that leaf litter turnover occurred in a year or less than a year.

Table 2: Effect of NPK fertilizer rate on decomposition rate per day, decay constant (*k*) and decomposition half-life (50%) values of green manure buried in 2014 and 2015

Treatment	Decomposition rate (% day <sup>-1</sup> )	Decay constant ( <i>k</i> )	Days to 50% decomposition (t <sub>50</sub> )
<b>NPK rate (kg ha<sup>-1</sup>)</b>			
<b>2014</b>			
0	2.1	0.304	22.8
150	2.4	0.338	20.5
300	3.1	0.424	16.3
450	4.8	0.658	10.6
<b>2015</b>			
0	2.6	0.359	19.3
150	2.7	0.381	18.2
300	3.5	0.497	13.9
450	4.8	0.658	10.5

*Nutrient release concentration in the litter*

The concentrations of N, P and K showed significant (*P* < 0.05) difference in all the year of study (Table 3). The leaf litter from the treatment showed similar pattern in all the nutrient added to the soil, the highest concentration of N (12.43 and 15.87 mg/g) significantly differ in 2014 and 2015 respectively. In 2014, P concentration increases with application of NPK fertilizer rate from control treatment to applied 300 kg ha<sup>-1</sup> beyond which there was no significant increase. The P concentration did not follow the same pattern where P concentration was significantly low in the control treatment than plot applied with higher NPK fertilizer rate (450 kg ha<sup>-1</sup>) that produced the highest P concentration. In 2014, K concentration significantly increase with additional application

fertilizer up to 300 kg ha<sup>-1</sup> beyond there was a decline on K concentration while in 2015, all fertilized plots had similar K concentration that was significantly higher than the control treatment. The release of nutrient may be attributed to N availability and quality of litter. This result corroborates with the findings of [33-35] that litter decomposition and release process depend on many factors, among which litter quality is known as one of the major drivers of organic matter degradability and decay rate. According to the nutrient transfer theory [36] adding fertilizer to leaf litter of poor quality may increase the decomposition rate of mixed leaf litter.

Table 3: Nutrient added through microbial decomposition of litter of lablab green manure at 70 days of incubation period in 2014 and 2015 dry season

Treatment	N concentration (mg/g)	P concentration (mg/g)	K concentration (mg/g)
<b>NPK rate (kg ha<sup>-1</sup>)</b>			
<b>2014</b>			
0	9.38c	1.99c	0.76d
150	11.07b	3.65b	4.98b
300	11.05b	4.40a	9.87a
450	12.43a	4.32a	3.81c
SE±	0.341	0.187	0.293
<b>2015</b>			
0	10.76c	0.89d	0.89b
150	14.22b	5.50b	3.65a
300	14.99b	3.69c	3.56a
450	15.87a	7.89a	3.65a
SE±	0.220	0.597	0.441

### Conclusion

The result from this study indicate that higher decomposition rate and nutrient release was enhanced by NPK fertilizer application. However, considerable amount organic matter and nutrient was added to the soil through the process of lablab litter decomposition. This would be significant for small-scale farmers. The nutrients added may also contribute to sustainable soil management practice because lablab green manure has the potential to decay rapidly and release nutrients for vegetable production.

### References

[1] Ali, M (1999). Evaluation of green manure technology in tropical low land rice system. *Field Crops Research*. 61: 61-78.  
 [2] Smil, V. (2000). *Enriching the Earth: Fritz Haber, Carboch, and the Transformation of World Food*, MIT Press, Boston.  
 [3] Tarawali, S. A. (1999). An approach for the evaluation of herbaceous legumes with multiple benefits. In: *Cover crops for Natural Resource Management in West Africa*. Proceedings of Workshop organized by IITA CIEPCA at Cotonou, Benin, 26-29, October.

[4] Baijukya, F.P. (2004). Adapting to change in banana-based farming systems of northwest Tanzania: The potential role of herbaceous legumes. Unpublished Ph.D. Thesis, Wageningen University, Wageningen, The Netherlands.  
 [5] Ibewiro, B., Sanginga N., Vanlauwe B. and Merky R. (2005). Nitrogen contribution from decomposing cover crop residues to maize in tropical derived savanna. *Nutrient Cycling in Agroecosystems* 57, 131-140.  
 [6] Woomer PL, Martin A, Albrecht A, Resck DVS. and Scharpenseel HW (1994). The importance and management of soil organic matter in the tropics: In: Woomer, PL, Swift MJ (eds) *The Biological Management of Tropical Soil Fertility*. Wiley, Chichester, UK, pp.47-80.  
 [7] Sanchez PA, Shepherd KD, Soule MJ, Place FM, Buresh RJ, Izac AM.N, Mokwunye AU, Kwesiga FR, Ndiritu DG and Woomer PL (1997). Soil fertility replenishment in Africa: an investment in natural resource capitol. In: Buresh RJ, Sanchez PA, Calhoun F (eds) *Replenishing Soil Fertility in Africa*, 51. Soil Science Society of America pp. 1-46. Special Publication.  
 [8] Sinaj S, Buerkert A, El-Hajj G, Bationo A, Traoré H. and Frossard E (2001). Effect of fertility management strategies on phosphorus bioavailability in four West African soils. *Plant and Soil* 233: 71-83.  
 [9] Tschakert P, Khouma M. and Sene M (2004). Biophysical potential for soil carbon sequestration in agricultural systems of the Old Peanut Basin of Senegal. *Journal of Arid. Environment*. 59: 511-533  
 [10] Yadvinder-Singh, Bijay-Singh, Khind CS (1992). Nutrient transformations in soils amended with green manures. *Adv. Soil Sci*. 20: 237- 309.  
 [11] Nagarajah, S., (1988). Green manuring in Rice farming. In: *Proceedings of Symposium on Sustainable Agriculture: International Rice Research Institute, 25-29 May, 1987 – IIRI*. Philippines. Pp 194-208.  
 [12] Jenkison, D.S and Ayanana A. (1997). Decomposition of Carbo-14 labelled plant materials under tropical conditions. *Soil society of American Journal* 41:912-915.  
 [13] Prescott, C. E. (2005). "Decomposition and mineralization of nutrients from litter and humus". In *Nutrient acquisition by plants: An ecological perspective*, Edited by: Bassiri Rad, H. Berlin: Springer.  
 [14] Yadvinder, S., Bijay, S., and Khind, C. S. (1992). Nutrient transformations in soils amended with green manures. *Advances in Soil Science*. 20, 237 – 309.  
 [15] Magid, J. and Kjaergaard C. (2001). Recovering decomposing plant residues from the particulate soil organic matter fraction: Size versus density separation. *Biology, Fertilizer and Soils*. 33:252-257.  
 [16] Moro, M. J. and Domingo, F. (2000) Litter decomposition in four woody species in a Mediterranean climate: Weight loss, N and P dynamics. *Annals of Botany*, 86: 1065-1071.



- [17] Blair, G. J. Conteh A and Lefroy R. D. B. (1995). Fate of organic matter and nutrients in upland agricultural system. In: *Soil organic matter management for sustainable agriculture* Lefroy, R. D. B., Blair G.J and Craswell E.T. (eds) ACIAR. Workshop proceedings. 56:41-49.
- [18] Cadisch, G., and Giller, K. E. (1997). Driven by nature: Plant Litter Quality and Decomposition. CABI Publishing, Wallingford, UK.
- [19] Myers RJK, Palm CA, Cuevas E, Gunatilleke IUN and Brossard M (1994). The synchronization of nutrient mineralization and plant nutrient demand. pp. 81-116. In Woome PL, Swift MJ (eds) *The biological management of tropical soil fertility*. Wiley-Sayce Publication. Chichester, UK.
- [20] Palm C.A and Sanchez P. A. (1991). Nitrogen Release from the Leaves of Some Tropical Legumes as Affected by Their Lignin and Polyphenolic Contents. *Soil Biol. Biochem* 23: (1) 83-88
- [21] Palm CA, Giller K, Mafongoya PL. and Swift MJ (2001). Management of organic matter in the tropics: translating theory into practice. *Nutr. Cycl. Agroecosyst.* 61: 63-75.
- [22] Wang WJ, Baldock JA, Dalal RC, Moody PW (2004). Decomposition dynamics of plant residues in relation to nitrogen availability and biochemistry determined by NMR and wet-chemical analysis. *Soil Biol. Biochem.* 36: 2045-2058.
- [23] Sewanne, K. K. and Simmons, J. (2003). Leaf litter decomposition. West Virginia Wesleyan College. [http://www.sewanee.edu/forestry\\_Geology](http://www.sewanee.edu/forestry_Geology)
- [24] Barthes BG, Penche A., Hien E., Deleorte P., Clermont-Dauphin C., Cournac L., Manlay RJ (2014). Effect of ramial wood amendment on sorghum production and topsoil quality in Sudano-sahelian Ecosystem (Centra Burkina Faso). *Agroforestry System* 89: (1) 81-93
- [25] Aber JD and Melillo JM (1982). Nitrogen immobilization in decaying hardwood leaf litter as a function of initial N and lignin content. *Canadian Journal of Botany.* 60: 2263-2269. <https://doi.org/10.1139/b82-277>.
- [26] Baggie I., Rowell DL., Robinson JS., and Warren GP. (2005). Decomposition and Phosphorus released from organic residues as affected by residue quality and added inorganic phosphorus. *Agroforestry Systems* 63: 125-131
- [27] Parton, W., Silver W.L., Burkel I. C., Grassens, L., Harmon, M. E., Currie, W. S., Kinge, J. Y., Adair E. C., Brandt L. A., Hart S. C., Fasth. B (2007). Global-Scale Similarities in Nitrogen Release Patterns During Long-Term Decomposition. 315: (5810) 361-364 [DOI: 10.1126/science.1134853](https://doi.org/10.1126/science.1134853)
- [27] Melillo JM., Aber JD and Muratere JF (1982). Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology* 63:621-627.
- [28] Fanin N, Hättenschwiler S, Barantal S, Schimann H and Fromin N (2011). Does variability in litter quality determine soil microbial respiration in an Amazonian rainforest? *Soil Biol Biochem* 43(5):1014–1022. <https://doi.org/10.1016/j.soilbio.2011.01.018>
- [29] Davidson EA., Janssen IA. And Luo Y. (2006). On the variability of respiration in terrestrial ecosystems: Moving beyond Q10. *Global Change Biology.* 12: 154-164.
- [30] Liu, C. and Sun, X. (2013). A review of ecological stoichiometry: basic knowledge and advances. *Ref Modul Earth Syst Environ Sci.* <https://doi.org/10.1016/B978-0-12-409548-9.05519-6>
- [31] Alvarez S. F. J., Sanchez G. R., Sanchez-Gallen I, and Gonzalez-Iturbe J. A. (1992). *Methods for the Study of Primary Productivity and Decomposition in Terrestrial Communities*, Department of Ecology, Faculty of Science, National Autonomous University of Mexico, 1992.
- [32] Liu P, Sun OJ, Huang J, Li L. and Han X (2007). Nonadditive effects of litter mixtures on decomposition and correlation with initial litter N and P concentrations in grassland plant species of northern China. *Biol Fertil Soils* 44(1):211–216.
- [33] Song F, Fan X. and Song R (2010) Review of mixed forest litter decomposition researches. *Acta Ecol Sin* 30(4):221–225.
- [34] Manzoni S, Trofymow JA, Jackson RB and Porporato A (2010) Stoichiometric controls on carbon, nitrogen, and phosphorus dynamics in decomposing litter. *Ecol Monogr* 80(1):89–106.
- [36] Schimel JP and Hättenschwiler S (2007) Nitrogen transfer between decomposing leaves of different N status. *Soil Biol Biochem* 39(7):1428–1436.