

Original Research Article

APPLICATION OF MULTIVARIATE PRINCIPAL COMPONENT ANALYSIS FOR CHARACTERIZATION OF LEAF LITTERS IN NORTHERN NIGERIA

ABSTRACT

~~The purpose of this~~ This study was to objectively describe the interrelationship between mass loss and leaf chemical parameters of litter species: *Khaya senegalensis*, *Mangifera indica*, *Gmelina arborea*, and *Eucalyptus camaldulensis* using principal component analysis. Leaf litters were analyzed for chemical compositions. Mass loss and ten litter chemical parameters such as ~~Organic~~ organic carbon, total nitrogen, total phosphorus, potassium, magnesium, calcium, sodium, total soluble polyphenol, total sulphur and carbon to nitrogen ratio were investigated. Principal Component Analysis (PCA) was used to identify the variation of litter chemical properties. The results showed significant relationships between mass loss and litter chemical parameters in PC₁ and PC₂ axes. *Khaya senegalensis* has the highest loadings (84%) followed by *Gmelina arborea* (77%), *Eucalyptus camaldulensis* (75.3%) and *Mangifera indica* (64.5%). In conclusion, *Khaya senegalensis* showed a propensity to have a faster response in driving biogeochemical cycling during decomposition.

Key words: Leaf litter, Chemical composition, Mass loss, Decomposition

Introduction

Litter mass loss or decay is the sum of carbon dioxide (CO_2) release and discharge of compounds, which contains both carbon compounds and nutrients (Brady and Weil 2010). According to Tenkiano and Chauvet (2018), the breakdown of leaf litter is an

important part of the global biogeochemical cycles that affect soil carbon storage, nutrient availability, and plant production. Designing agroforestry systems for soil conservation and improvement requires an evaluation of the quality of the litter and the rate of leaf biomass breakdown (Parthey and Thevathasan, 2013, Isaac and Nair, 2006). The management of chemical element and compound levels in agroforestry systems is once again emphasized (Xiao et al. 2019, Tenkiano and Chauvet, 2018). Many studies concluded that the rate of leaf litter decomposition depended on tree species, the chemical composition of the leaves, and environmental factors such as temperature and soil moisture (Trinsoutrotet *et al.*, 2000; Tu *et al.*, 2014).

A multivariate technique called principal component analysis (PCA) can be used to reduce the dimensionality of such datasets, improving their interpretability while minimizing information loss (Jolliffe, 2002). It accomplishes this by producing fresh, uncorrelated variables that maximize variance one after the other. As a result, PCA is an adaptive data analysis technique (Diamantaras and Kung, 1996). Finding such new variables, the principal components, reduces to solving an eigenvalue/eigenvector issue, and the new variables are specified by the dataset at hand, not a priori. Many researchers have used the independent factor scores derived from multivariate technique of principal component factor analysis to soil and leaf litter properties (Salehi and Zahedi Amiri, 2005; Kooch et al., 2021). The modelling component of leaf litter decomposition is widely reported in scientific literatures (Corney *et al.*, 2006; Macciotta and Gaspa, 2009). In Sub-Saharan Africa, there is dearth of information on the interrelationships among mass loss and litter chemistry traits of leaf litters using a multivariate approach. Understanding leaf litter decomposition dynamics is imperative owing to nutrient release rates and synchronization. The overarching aim is to use principal components analysis to

account for interrelationship between mass loss and chemical parameters of leaf litters in Northern Nigeria.

MATERIAL AND METHODS

Experimental Site and Climatic Conditions

The study was carried out at Institute for Agricultural Research, Ahmadu Bello University, Zaria, Kaduna State, Northern Guinea Savannah zone of Nigeria field (IAR plot R14). The experimental area ~~in (Samaru)~~ has a geo reference: ~~of latitude~~ $10^{\circ}10' 0''$ N and ~~longitude~~ $7^{\circ}37' 60''$ E and ~~an altitude of~~ 688 m ~~above sea level~~ a.s.l. (Goggle earth, 2023). This region is characterized by two distinct seasons: the dry season comprising the cold dry period also known as the harmattan ~~(November-December)~~ and the hot dry period ~~between~~ (April-June) as well as a warm rainy season ~~(between July-September)~~ with rainfall of about 1060mm annually. October and March constitute traditional months between rainy and cold dry season and between hot dry period and rainy season. Warm conditions and high relative humidity prevail during rainy season. The region is characterized by a lot of leaf falls during the dry season and very high temperatures which affect plant growth and developmental process (IAR Metro station, 2021).

Collection and Processing of Leaf Samples

Fall leaves of African mahogany ~~(*Khayasenegalensis*)~~; ~~Mangemango~~ ~~(*Mangifera indica*)~~; Beech wood ~~(*Gmelina arborea*)~~; and ~~River-river~~ red gum ~~(*Eucalyptus camaldulensis*)~~, were picked from the selected tree species. The collected leaf litter samples were cleaned and all sediments and dirt particles were removed by using a soft brush with running tap water followed by final rinsing in distilled water. Each sample was air-dried under shade at the Department of Soil Science Laboratory.

Chemical Analysis of Leaf Litter

Air dried leaf litter samples were ground in mortar and sieved through a 1mm mesh size sieve. The fine powder was used for the estimation of C, N, P, K, Ca, Mg, lignin and total soluble polyphenols. The standard procedures that were adopted for the chemical analysis are presented below.

Total carbon

The total carbon content was determined by igniting the samples at 550 °C using the Walkey Black method as reviewed by (Okaleboet *et al.*, 2002).

Total nitrogen

Nitrogen content in fresh leaf litter was determined by digesting 0.1 g of samples in 5 ml of concentrated sulphuric acid using digestion mixture (sodium sulphate: copper sulphate in 10:4 ratio) and nitrogen in the digest was determined by Kjeldhal's method as reviewed by Saez-Plaza *et al.*, (2013).

Total phosphorus

Approximately 0.2g of the powdered leaf sample was digested in tri-acid mixture (nitric acid: perchloric acid: sulphuric acid in 1:1:3 ratio) and the digest was made up to 100 ml. A known quantity of aliquot was taken to determine the phosphorus content by following chlorostannus reduced molybdophosphoric blue colour method in sulphuric acid system (Bray and Kurtz, 1945) and the colour intensity was read at 660 nm in UVspectrophotometer.

Total basic cations

Calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na) were determined using flame photometry and Atomic Absorption Spectrophotometer (AAS) as appropriate after wet digestion (Anderson *et al.*, 2017).

Sulphur

This was determined turbidimetrically using spectrophotometer to read for absorbance at wavelength of 430nm. (Tabatabai and Bremmer, 1970)

Total soluble polyphenols

Total soluble polyphenol was determined in the Pharmacognosy and Drug Development Laboratory of the Department of Pharmacognosy, Ahmadu Bello University, Zaria using the Follin-Ciocalteu's method (Moyer *et al.*, 2002).

Data Analysis

Principal component analysis of morphometric measures and their contribution to mass loss was analyze using the factor procedure of SAS (2014). The correlations coefficient of mass loss and litter chemical parameters was determined. From the correlation matrix, data for the principal component factor analysis was generated. Principal component analysis (Everitt *et al.*, 2001) is a method of transforming the variables in a multivariate data set X_1, X_2, \dots, X_p into variables. Y_1, Y_2, \dots, Y_p which are uncorrelated with each other and account for the decreasing proportion of the total variant of the original variable.

Result and discussion

Figure1 shows the relationship between mass loss and chemical composition in litter of *Khaya senegalensis*. Mass loss had high negative and significant ($p < 0.05$) association with potassium,

Figure1: Principal component matrix of mass loss and chemical parameters in *Eucalyptus Camaldulensis*. TN = total nitrogen, TK = total potassium, OC = organic carbon, TP = total phosphorus, TPC = total phenol content, C: N = carbon to nitrogen ratio, N: P = Nitrogen to phosphorus ratio, Mg = magnesium, Ca = Calcium, Na = sodium, S = Sulphur.

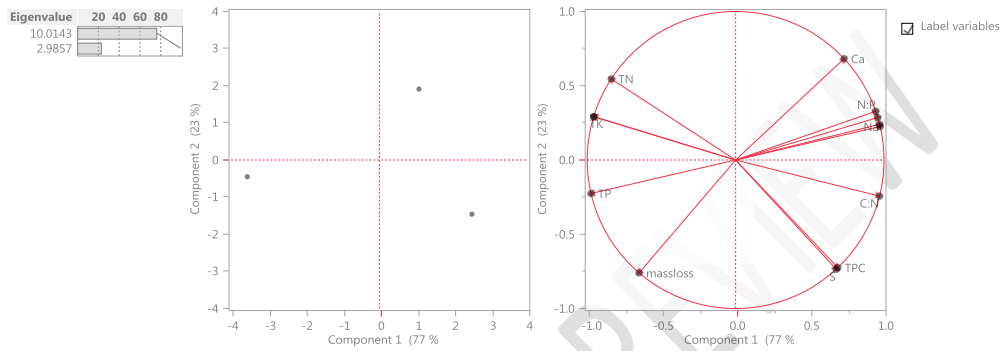


Figure 2: Principal component matrix of mass loss and chemical parameters in *Gmelina arborea*. TN = total nitrogen, TK = total potassium, OC = organic carbon, TP = total phosphorus, TPC = total phenol content, C:N = carbon to nitrogen ratio, N:P = Nitrogen to phosphorus ratio, Mg = magnesium, Ca = Calcium, Na = sodium, S = Sulphur.

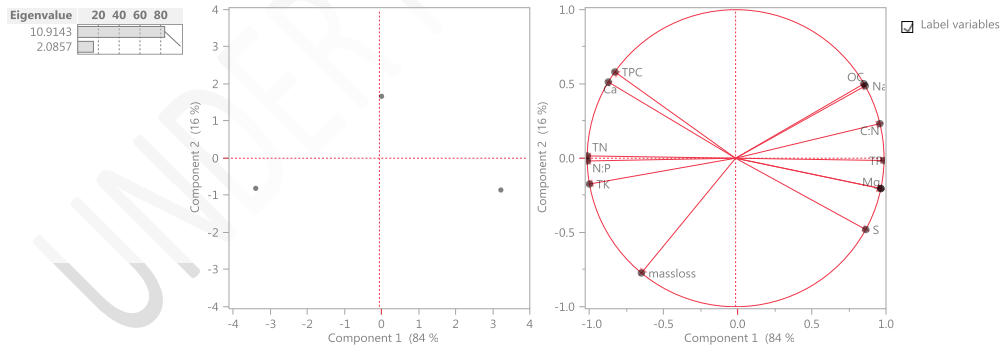


Figure 3: Principal component matrix of mass loss and chemical parameters in *Khaya senegalensis*. TN = total nitrogen, TK = total potassium, OC = organic carbon, TP = total phosphorus, TPC = total phenol content, C:N = carbon to nitrogen ratio, N:P = Nitrogen to phosphorus ratio, Mg = magnesium, Ca = Calcium, Na = sodium, S = Sulphur.

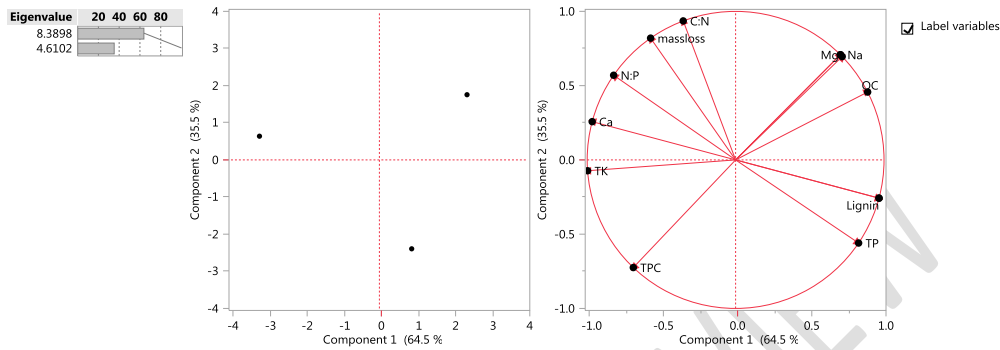


Figure 4: Principal component matrix of mass loss and chemical parameters in *Magnifera indica*. TN = total nitrogen, TK = total potassium, OC = organic carbon, TP = total phosphorus, TPC = total phenol content, C: N = carbon to nitrogen ratio, N : P = Nitrogen to phosphorus ratio, Mg = magnesium, Ca = Calcium, Na = sodium, S = Sulphur.

In *Mangifera indica*, mass loss was strongly and negatively correlated with magnesium and total phosphorus which agrees with the observations of several studies (Tian *et al.*, 1992; Kim *et al.*, 1998). The positive relationship between carbon:nitrogen ratio and nitrogen:potassium ratio was based on the premise that nitrogen concentration limits the activity of decomposers (Swift *et al.*, 1979). In *Gmelina arborea*, increase in mass loss will significantly cause a reduction in organic carbon, calcium, sodium, lignin, total phenol content and C: N this agrees with trend reported by Berg and Ekbohm (1991) who observed that mass-loss rates and late-stage litter negatively to carbon, calcium and sodium (Berg and Ekbohm, 1991). In *Eucalyptus camaldulensis*, mass loss was strongly, negatively and highly correlated with potassium, sulphur, total phenol content and C: N ratio. Many studies showed that litter mass loss was strongly correlated with nitrogen, potassium, sulphur and C:N ratio (Kim *et al.*, 1998) (Vitousek *et al.*, 1994; Aerts and Caluwe, 1997). The concept of the regulatory effect of C:N ratio was based on the fact that nitrogen concentration limits the activity of decomposers (Swift *et al.*, 1979). Judging from the positive

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correlations between mass loss and potassium, magnesium, sulphur, nitrogen and C:N ratio, this implies good predictability of mass loss of litters of *Eucalyptus camaldulensis*, which agreed with the trend of relationship in the hardwood leaf litter (Taylor *et al.*, 1989) and native tree species raised on coal mine in India (Singh *et al.*, 1999).

CONCLUSIONS

Multivariate PCA showed noticeable variations among leaf litters parameters. Since these methods are of high accuracy and have different abilities, they could be used for indicator of soil health through litter decomposition. The ~~principal-main~~ component factor analysis led to an objective simultaneous analysis of ~~Organic-organic~~ carbon, total nitrogen, total phosphorus, potassium, magnesium, calcium, sodium, total soluble polyphenol, total sulphur and carbon to nitrogen ratio in different leaf litters rather than on individual basis. This resulted in the reduction of the leaf litters chemical parameters to two PCs in each leaf litter species.

REFERENCES

- Aerts, R. and Caluwe, H. (1997). Nutritional and plant mediated controls on leaf litter decomposition of *Carex* species. *Ecology*; 78(1): 244-260.
- Anderson, C., Peterson, M. and Curtin, D. (2017). Base cations, K⁺ and Ca²⁺, have contrasting effects on soil carbon, nitrogen and denitrification dynamics as pH rises. *Soil Biology and Biochemistry*, 113: 99-107.
- Berg, B., and Ekbohm, G. (1991). Litter mass loss rates and decomposition patterns in some needle and leaf litter types. Long-term decomposition in a Scots pine forest VII. *Canadian Journal of Botany*; 69: 1449-1456.
- Brady, N. and Weil, R. (2010) Nutrient Cycles and Soil Fertility. In: Anthony, V.R., Ed., Elements of the Nature and Properties of Soils, 3rd Edition, Pearson Education Inc, Upper Saddle River, NJ, 396-420.
- Bray, R. H. and Kurtz, L. (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil Science*; 59(1): 39-46.

- Corney, P.M., Leduc, M.G., Smart, S.M., Kirby, K.J., Bunce, R.G.H. and Marrs, R.H. (2006). Relationships between the species composition of forest field-layer vegetation and environmental drivers, assessed using a national scale survey. *Journal of Ecology*; 94: 383-401.
- Diamantaras KI, Kung SY. (1996). Principal component neural networks: theory and applications. New York, NY: Wiley.
- Everitt, B. S., Landau, S. and Leese, M. (2001). *Cluster Analysis*. 4th edition. Arnold Publisher, London.
- Goggle Earth (2023). Goggle Earth Imagery
- Institute for Agricultural Research Metrological station, IARMS (2021). Metrological data from IAR metrological station, Ahmadu Bello University, Samaru, Zaria Nigeria.
- Isaac, S.R. and Nair, M.A. (2006). Litter dynamics of six multipurpose trees in a homegarden in Southern Kerala, India. *Agroforest System*;67: 203–213.
- Jolliffe IT. 2002 Principal component analysis, 2nd edn. New York, NY: Springer-Verlag.
- Kooch, Y., Ghorbanzadeh, N., Wirth, S., Novara, A. Shah Piri, A. (2021). Soil functional indicators in a mountain forest-rangeland mosaic of northern Iran. *Ecological Indicators*; 126:107672
- Kim, J.S., Chappelka, A.H. and Miller-Goodman, M.S. (1998). Decomposition of Blackberry and Broomsedge Bluestem as influenced by ozone. *Journal of Environmental Quality*; 27: 953-960.
- Liu, P., Huang, J., Sun, O.J. and Han, X. (2010). Litter decomposition and nutrient release as affected by soil nitrogen availability and litter quality in a semiarid grassland ecosystem. *Oecologia*;162:771-780.
- Macciotta, N.P.P., Gaspa, G., Steri, R., Nicolazzi, E.L., Dimauro, C., Pieramati, C. and Cappio-Borlino, A. (2010). Using eigenvalues as variance priors in the prediction of genomic breeding values by principal component analysis. *Journal of Dairy Science*; 93(6): 2765-2774.
- Moyer, R. A., Hummer, K. E., Finn, C. E., Frei, B. and Wrolstad, R. E. (2002). Anthocyanins, phenolics, and antioxidant capacity in diverse small fruits: *Vaccinium*, *Rubus*, and *Ribes*. *Journal of Agriculture and Food Chemistry*; 50 (3): 519–525.
- Okalebo, J. R., Gathua, K. W. and Woomer, P. L. (2002). Laboratory methods of soil analysis: A working manual, second edition. TSBR-CIAT and SACRED Africa, Nairobi, Kenya
- Partey, S.T. and Thavathasan, N.V. (2013). Agronomic potentials of rarely used agroforestry species for smallholder agriculture in sub-Saharan Africa: an exploratory study. *Communication in soil science and plant analysis*; 44 (11), 1733 - 1746.

- Saez-Plaza, Michalowski, T., Navas, M.J. and Asuero, A.G. (2013). An overview of the Kjeldahl method of nitrogen determination part 1. Early history, chemistry of the procedure, and titrimetric finish. *Critical Review in Analytical Chemistry*; 4: 43-45.
- Salehi, A. and Amiri, G. Z. (2005). Study of physical and chemical soil properties variations using principal component analysis method in the forest, North of Iran. *Caspian Journal of Environmental Sciences*; 3(2): 131-137.
- Singh, K.P., Singh, P.K. and Tripathy, S.K. (1999). Litterfall, litter decomposition and nutrient release patterns in four native tree species raised on coal mine spoil at Singrauli, India. *Biological Fertilizers and Soils*; 29: 371-378.
- Swift, J.A., Heal, O.W. and Anderson, J.M. (1979). *Decomposition in Terrestrial Ecosystems*. Oxford: Blackwell Scientific Publications.
- Tabatabai, M.A. and Bremner, J.M. (1970). A simple turbidimetric method of determining total sulphur in plant materials. *Agronomy Journal*; 62 (6): 805-806.
- Taylor, B.R., Parkinson, D. and Parsons W.F.J. (1989). Nitrogen and lignin control of hardwood leaf decomposition dynamics. *Ecology*; 63: 621-626.
- Tenkiano, N. Sia, D. and Chauvet, É. (2018). Leaf litter decomposition in Guinean savannah streams. *Inland Waters*; 8 (4). 413-421.
- Tian, G., Kang, B.T. and Brussard, L. (1992). Biological effect of plant residues with contrasting chemical composition under humid tropical conditions- Decomposition and nutrient release. *Soil Biology and Biochemistry*; 24: 1051-1060.
- Trinsoutrot I, Recous S, Bentz B, Lineres M, Cheneby D, Nicolardot B. (2000). Biochemical quality of crop residues and carbon and nitrogen mineralization kinetics under nonlimiting nitrogen conditions. *Soil Science Society of America Journal*; 64:918-926.
- Tu L., Hu H., Hu T., Jian Z., Xianwei L., Li L., et al., (2014). Litterfall, litter decomposition, and nutrient dynamics in two subtropical bamboo plantations of China. *Pedosphere*; 24 (01), 84-97.
- Vitousek, P.M., Turner, D.R., Parton, W.J. and Sanford R.L. (1994). Litter decomposition on the Mauna Loa environmental matrix, Hawaii: patterns, mechanisms and models. *Ecology*, 75: 418-429.
- Xiao, W., Han, Y.H., Chen, Kumar, Chen, C. and Guan, Q. (2019). Multiple interactions between tree composition and diversity and microbial diversity underly litter decomposition. *Geoderma*; 341: 161-171.