*Original Research Article*

Comparative Analysis of Termite Mound Soils and Their Adjacent Soils Under Horticulture, Bamboo And Forest Land Uses In Acid Soils Of Assam

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ABSTRACT

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| **Aims:** The aim of this study was to compare the soil physico-chemical and microbiological properties between the termite mounds and their adjacent soils using standard procedures. **Study design:** A one way ANOVA was performed to compare the soil properties between the termite mound and their adjacent soils.**Place and Duration of Study:** Department of Soil Science, Assam Agricultural University. From January 2019 to July 2020.**Methodology:** Three termite mounds each were collected from the Horticulture, Bamboo and forest Land Uses with three samples collected from each mound. One composite sample was collected from about one meter distance from the termite mounds in each case. The samples were then analyzed for physico-chemical and biological properties using standard analysis procedures.**Results:** The clay content varied from 31.02% to 33.68% in the termite mounds which was significantly higher than the adjacent soils where it ranged from 24.92% to 26.28%. The Nitrogen, P2O5 and K2O content ranged from 143 kgha-1 to 182.58 kgha-1,41.22 kgha-1 to 65.46 kgha-1 and from 116.26 kgha-1 to 132.76 kgha-1 respectively in the termite mounds while they ranged from 112.89% to 135.75%, 37.25% to 58.69% and from 78.90% to 82.50% in the adjacent soils. The activity of *dehydrogenase* was 86.38 µg TPF/g soil/24hr in the termite mounds under horticulture land use which was the highest while the highest dehydrogenase activity in the adjacent soils was 85.17 µg TPF/g soil/24hr. The Soil Quality Index was found to be maximum in case of Horticulture (12.35%) followed by Bamboo (10.40%) and Forest (9.80%). **Conclusion:** It was observed that the termite mound soil has properties different than their adjacent soils. The termite mound soil was found to be higher in bulk density and water holding capacity compared to surrounding soil. They were also richer in clay, organic carbon, and concentrations of N, P, K, S, Ca, and Mg and enzymatic activities than their adjacent soils. Total acidity, Potential acidity and Exchangeable Al+ were found to be lower in the mounds as compared to the adjacent soils under all the land uses. |

*Keywords: termite, land uses, soil properties, termite mounds, Soil Quality Index*

1. INTRODUCTION

Soil is a natural system composed of minerals, organic matter and pore spaces. It acts as a habitat for a wide range of macro as well as microorganisms like bacteria, fungi, ants, earthworms, termites etc. For the purpose of our study, we are focused on the soil organisms “termites” in terms of the soil properties of their mounds.

Termites are mostly soil inhabiting macroorganisms that taxonomically belong to the order Isoptera, phylum: Arthropoda, class: Insecta, kingdom: Animalia. Reported information revealed that about 2500 species of termites with seven families belong to the order Isoptera(Waller and La Fage, 1987) and about 75% of them are classified as soil feeding termites (Vats and Aggarwal, 2011). Due to their impact on soil characteristics, termites are extensively studied around the world with respect to their mounds. They can also be termed as "ecosystem engineers" (Dangerfield *et al.,* 1998) because of their capacity to alter and disrupt soil processes and thereby play a great role in making nutrients available in low nutrient environment (Avitabile *et al.,.,* 2015).

The soil collected by termites for building their mounds is brought from great depths and distances and these are cemented together by using their salivary secretions to build earthen mounds (Vats and Aggarwal, 2011). This is done for their protection and to provide favourable micro-climatic conditions for the colony. Termite mounds have some underground structures as a result of which, the site becomes very porous with high water infiltration ( Leónard and Rajot, 2001).They were also richer in clay, organic carbon, and concentrations of N, P, K, S, Ca, and Mg and enzymatic activities than their adjacent soils (Ohkuma, 2003).

The physico chemical properties of the soils are also improved by termite activities among which increase in clay content is very remarkable even to the extent of 20% or more than the adjacent soil (Donovan *et aI.,* 2001). Termites can transform clay, k-feldspars into kaolinite and use it as a cementing agent during mound construction and synthesize organo-metal complexes (Adekayode *et al.,* 2009). The termite species and their feeding habits are also known to influence the mound soil characteristics (Lopez-Hernandez *et al.,* 2006). The termite mounds thus prove to be sites of higher nutrient concentration.

Due to erosion, the materials that are accumulated in the mounds get redistributed which causes changes in soil microstructure and the fertility in the adjacent areas (Shaefer, 2001). The redistribution of the mound materials is however influenced by washing away and movement of nutrients from the mounds and also on the type of species present (Rückamp *et al.,* 2009).

In Assam, very few studies are available with respect to the soil transformations caused by termites or the properties of their mounds. Study on mound characteristics with respect to variation in land use is also very meager. Considering the above facts, the study was undertaken to explore the differences in termite mound characteristics under different land uses.

2. material and methods

**2.1 Site Description**

The Horticulture and Bamboo land uses were selected from Na- Ali Dhekiajuli Konhar Gaon, Jorhat, Assam. (26.66’E latitude, 92.49’ N longitude). The forest selected for sample collection was located in Hatigarh, Garmur, Jorhat district of Assam (latitude 26°74’ E, longitude 94°23’N).

**2.2 Soil Sample Collection**

For the purpose of this study, three termite mounds from each of the land use were selected for soil sampling which gives a total of nine mounds. A composite sample was collected from the soil surrounding the termite mounds**.**

**2.2 Soil Sample Analysis**

Analysis of the collected soil samples was done following standard procedures. Soil samples were analyzed for bulk density by core sampler (Blake and Hartge 1986), particle density and water holding capacity by using Keen Rackzowski box as described by Baruah and Barthakur (1997),texture by International Pipette Method (ISSS, 1929),organic carbon (Walkley and Black 1934) ,pH taking soil :water ratio of 1:2.5 (w/v)at 25°c, EC with conductivity bridge at 25°c (Jackson, 1973),CEC by neutral normal ammonium acetate (NH4OAc) leaching method (Jackson,1973), available nitrogen by alkaline potassium permanganate method (Subbiah and Asija, 1956), available phosphorus by Bray’s I method (Bray and Kurtz 1945), available potassium by extraction with neutral normal ammonium acetate method (Jackson 1973), available sulphur by monocalcium phosphate extraction procedure (Ensminger, 1954), exchangeable calcium magnesium by versene titration method (Jackson 1973), soil acidity components by Baruah and Barthakur (1997), *dehydrogenase* activity by (Casida *et al.* 1964) and FDA hydrolysis by (Adam and Duncan, 2001).

**2.3 Statistical Analysis**

A one-way ANOVA test was carried out to compare the properties of the termite mound soil and adjacent soils. SQI was developed to integrate the soil physical, chemical and micro biological properties into a single index number, which can be used to assess aggradation and degradation status with reference to adjacent soils of termite mounds through mean weighted index. This was done as per the protocol given by Dalal and Moloney (2012).

3. results and discussion

3.1 Physical Properties

The physical properties of the termite mound soils and their surrounding soils are mentioned in table 1. The clay content varied from 31.02% to 33.68% in the termite mounds which was significantly higher than the adjacent soils where it ranged from 24.92% to 26.28%. Clay and silt content in the termite mounds were higher and sand content was lower in all the land uses (*P*<0.05%). Sarcinelli *et al.* (2013),Eneji *et al.*(2015), Deke *et al.*(2016) reported similar results. Higher clay content in the mounds compared to that of the adjacent soils might be due to preferential selection of finer particles by the termites for the construction of mounds (Donovan *et al.,*2001). The lower sand content of the mound soil as compared to the adjacent soil could be because of the preferential transport and incorporation of clay to the detriment of sand particles by termites (Ekundayo and Aghatise, 1996). The bulk density of the walls of the termite mound soils was higher compared to the surrounding soils (*P*<0.05%). It varied from 1.38 g/cc to 1.19 g/cc in the termite mounds while from 1.34 g/cc to 1.34 g/cc. This can be attributed to the termites’ repacking and cementing ability which causes the compaction of the mound soil (Arshad, 1982; Sileshi *et al.,*2010).There was however no significant difference in terms of the particle density. The Water Holding Capacity of the soils of the mounds was observed to be higher than that of the adjacent soils under all the land uses (*P*<0.05%). Rajagopal reported similar results in 1983. Traore *et al.* (2019) reported that this is due to higher clay content of the soils of termite mound than their adjacent soil.

**Table 1. Physical properties of the termite mounds and their adjacent soils under different land uses**

|  |  |  |  |
| --- | --- | --- | --- |
| **PROPERTIES** | **Horticulture** | **Bamboo** | **Forest** |
| **Termite mound** | **Adjacent soil** | **Termite mound** | **Adjacent soil** | **Termite mound** | **Adjacent soil** |
| **Sand (%)** | 45.47a | 52.36a | 47.31b | 54.58b | 48.61c | 55.27c |
| **Silt (%)** | 20.85 | 19.82 | 21.67 | 20.50 | 20.28d | 18.88d |
| **Clay (%)** | 33.68e | 26.28e | 31.02e | 24.92e | 31.11f | 25.85f |
| **Bulk density. (g/cc)** | 1.27g | 1.19g | 1.38 | 1.34 | 1.19 | 1.14 |
| **Particle density (g/cc)** | 2.49 | 2.40 | 2.46 | 2.40 | 2.39 | 2.46 |
| **Water holding capacity (%)** | 30.88h | 27.58h | 32.01i | 29.56i | 32.42j | 29.35j |

\*\*The values with similar letters differ significantly at 5% significance level.

**3.2 Chemical properties**

The pH of the termite mounds ranged from 5.66 to 5.28 while it ranged from 5.11 to 4.99 in the adjacent soils. The pH in the termite mound soils was significantly higher compared to that of the adjacent soils (*P*<0.05%). Higher pH can be attributed to the higher content of exchangeable basic cations K+ , Ca2+ and Mg2+ leading to an increase in base saturation of termite mound soil with respect to the adjacent soils (Kooyman and Onck, 1987) (Table 2). There was not much difference in the electrical conductivity between the termite mounds and their surrounding soils under all the land uses. However, their values indicate that the soils under all the land uses in the termite mounds and their surrounding soils were not saline (Dhembare, 2013).Organic matter content was measured as higher in the termite mounds than the surrounding soils under all the land uses (*P*<0.05%). It ranged from 1.56% to 1.53% in the termite mound soils and from 1.17 to 1.15 %. This might be because the termites forage the organic matter and accumulate it in their mounds (Baig *et al.,* 2018 and Sarcinelli *et al.,*2009). Similar results were also obtained by Vats and Aggarwal (2011). The Cation Exchange Capacity of the soils in the mounds was comparatively higher than the soils of the adjoining areas (*P*<0.05%). It varied from 8.18cmol(p+)kg-1 to 7.90 cmol(p+)kg-1 in the termite mound soil and from 7.6 cmol(p+)kg-1  to 6.98 cmol(p+)kg-1  in the adjacent soils. This higher CEC in the mounds is due to a higher content of clay and organic matter compared to the adjacent soils which increases the chemically active surface area (Eneji *et al.,*2015; Jouquet *et al.,* 2011; Krohmer, 2004; Holt and Lepage,2000)

**Table 2. Chemical properties of the termite mounds and their adjacent soils under different land uses**

|  |  |  |  |
| --- | --- | --- | --- |
| **PROPERTIES** | **Horticulture** | **Bamboo** | **Forest** |
| **Termite mound** | **Adjacent soil** | **Termite mound** | **Adjacent soil** | **Termite mound** | **Adjacent soil** |
| **pH** | 5.28a | 4.91a | 5.4b | 5.11b | 5.66c | 4.98c |
| **EC (dS/m)** | 0.04 | 0.05 | 0.07 | 0.05 | 0.05 | 0.04 |
| **OC (%)** | 1.56d | 1.17d | 1.53e | 1.16e | 1.54f | 1.15f |
| **CEC [cmol(p+)kg-1]** | 7.9g | 6.98g | 8.14h | 7.26h | 8.18i | 7.6 |

\*\*The values with similar letters differ significantly at 5% significance level.

**3.3 Available Nutrients**

The Nitrogen, P2O5 and K2O content ranged from 143 kgha-1 to 182.58 kgha-1,41.22 kgha-1 to 65.46 kgha-1 and from 116.26 kgha-1 to 132.76 kgha-1 respectively in the termite mounds while they ranged from 112.89% to 135.75%, 37.25% to 58.69% and from 78.90% to 82.50% in the adjacent soils. Nitrogen as well as Phosphorus content in the soils of termite mounds was higher compared to their adjacent soils under all the land uses (*P*<0.05%). Similar results were obtained by Eneji *et al.* (2015) and Lopez-Hernandez *et al.*(2006). The consumption of humus by the soil feeding termites, accumulation of N2 in termite biomass and its subsequent release into the mounds after their death as well the accumulation of termite faecal matter was speculated as an input for higher Nitrogen and Phosphorus content in the termite mound soil than their adjacent soil. Mineralization of organic matter by the termites could also be a reason for higher N content in the mounds (Deke *et al.,*2016). According to Rowland *et al.* (1993), termite excreta rich in N2 and nitrate levels could also be the reason for higher nitrogen content in the mounds. Sulphur content was also found to be higher in the mound soil as compared to the soils of the adjacent areas under all the land uses. Potassium, Calcium and Magnesium content was found to be higher in the mound soils with respect to the soils of the adjacent areas under all the studied land uses (*P*<0.05%). These observations are in agreement with that of Deke *et al.* (2016), Sarcinelli and Schaefer (2009) and Dhembare (2013). Schaefer (2001) reported that this might be due to change and movement of some primary minerals from sources due to the action of soil turnover by the termites. Moreover, some potassium may also be released from the termite saliva and some microbes that was bound to clay (Jouquet *et al*., 2011). Calcium and Potassium content was still higher in the soils of termite mounds as compared to that of their adjacent soils. Table 3 presents the available nutrients in the termite mounds and their adjacent soils.

**Table 3. Available nutrients in the termite mounds and their adjacent soils under different land uses**

|  |  |  |  |
| --- | --- | --- | --- |
| **PROPERTIES** | **Horticulture** | **Bamboo** | **Forest** |
| **Termite mound** | **Adjacent soil** | **Termite mound** | **Adjacent soil** | **Termite mound** | **Adjacent soil** |
| **N (kg/ha)** | 175.62a | 135.75a | 182.58b | 112.89b | 143c | 114c |
| **P2O5 (kg ha-1)** | 53.16d | 45.40d | 65.46e | 58.69e | 41.22f | 37.25f |
| **K2O (kg ha-1)** | 132.76g | 79.52g | 116.26h | 82.5h | 124.53i | 78.9i |
| **Ca [cmol (p+)kg-1]** | 2.9j | 2.33j | 2.67k | 2.17k | 1.87l | 1.03l |
| **Mg [cmol (p+)kg-1]** | 1.77m | 1.08m | 2.07n | 1.48n | 1.87o | 0.88o |
| **S (ppm)** | 35.78p | 32.15p | 39.66q | 35.46q | 21.99r | 19.89r |

\*\*The values with similar letters differ significantly at 5% significance level.

**3.4 Acidity Components**

Total acidity, potential acidity and exchangeable Al+ were found to be lower in the mounds as compared to the adjacent soils under all the land uses(*P*<0.05%) (Table 4). This effect can be seen in the form of pH as presented in Table 2. The lower Al+ in the mounds might be due to its precipitation as Al3+complexation with organic matter which is present in higher amount in the mounds compared to the soils of the adjoining areas (Sarcinelli *et al.,* 2009, de Lima *et al.,*2018). Much literature is not available for acidity components in termite mounds.

**Table 4. Acidity components in the termite mounds and their adjacent soils under different land uses**

|  |  |  |  |
| --- | --- | --- | --- |
| **PROPERTIES** | **Horticulture** | **Bamboo** | **Forest** |
| **Termite mound** | **Adjacent soil** | **Termite mound** | **Adjacent soil** | **Termite mound** | **Adjacent soil** |
| **Total Acidity[cmol (p+)kg-1]** | 2.47a | 2.96a | 2.63b | 3.29b | 2.50 | 2.78 |
| **Exch. Acidity[cmol (p+)kg-1]** | 2.18c | 2.84c | 2.59d | 3.11d | 1.44e | 1.96e |
| **Exch. Al[cmol (p+)kg-1]** | 1.69f | 2.37f | 2.26g | 2.70g | 1.29h | 1.63h |
| **Exch. H[cmol (p+)kg-1]** | 0.44 | 0.47 | 0.33 | 0.41 | 0.23i | 0.32i |

\*\*The values with similar letters differ significantly at 5% significance level.

**3.5 Microbiological Properties**

The activity of dehydrogenase enzyme as well as FDA values was measured as higher (*P<0.05)* in the mound soil than the adjoining areas under all the land uses (Table 5).It was observed to be 86.38 µg TPF/g soil/24hr in the termite mounds and 85.17 µg TPF/g soil/24hr in the adjacent soils under horticulture land use, 67.30 µg TPF/g soil/24hr in the termite mound soil and 65.54 µg TPF/g soil/24hr in the adjacent soil under bamboo land use and 79.74 µg TPF/g soil/24hr in the termite mound soils and 77.02 µg TPF/g soil/24hr under forest land use. FDA values ranged from 2.60 μg fluorescein/g/hr to 7.14μg fluorescein/g/hr in the termite mounds while it ranged from Subi and Merlene Sheela (2020) mentioned Dehydrogenase as one of the key enzymes of oxydoreductase group which is an important indicator of microbial activity of the soil. Higher value of FDA and dehydrogenase in the mounds maybe due to their higher bacterial population which again might be due to higher organic carbon content in the mounds (Kumar *et al*., 2018).

**Table 5. *Dehydrogenase* activity and FDA hydrolysis values in the termite mounds and their adjacent soils under different land uses**

|  |  |  |  |
| --- | --- | --- | --- |
| **PROPERTIES** | **Horticulture** | **Bamboo** | **Forest** |
| **Termite mound** | **Adjacent soil** | **Termite mound** | **Adjacent soil** | **Termite mound** | **Adjacent soil** |
| **Dehydrogenase (µg TPF/g soil/24hr)** | 86.38a | 85.17a | 67.30b | 65.54b | 79.74c | 77.02c |
| **FDA (μg fluorescein/g/hr)** | 7.14d | 5.61d | 2.60e | 1.64e | 6.22f | 5.56f |

\*\*The values with similar letters differ significantly at 5% significance level.

**3.6 Aggradation and Degradation through Soil Quality Index**

The SQI was developed to integrate 26 measured soil physical, chemical and microbiological properties into a single index number, which can be used to assess aggradation and degradation status with reference to the adjacent soils of termite mounds through mean weighted index.

SQI observed under each land use were compared with the adjoining soil to assess the degree of aggradation or degradation (Table 6).

**Table 6. The Soil Quality Index (SQI) of the land uses and their subsequent aggradation or degradation status**

|  |  |  |
| --- | --- | --- |
| **Land use** | **SQI** | **Aggradation/Degradation** |
| Horticulture | 12.35 | Aggradation |
| Bamboo | 10.40 | Aggradation |
| Forest | 9.80 | Aggradation |

The SQI of the different land uses were of the order: Horticulture>Bamboo>Forest.

Based on the SQI value, it can be concluded that soil under Horticulture land use (SQI 12.35) is highly enriched by the termite mounds followed by bamboo and forest land use.

4. Conclusion

Soil from termite mounds is very rich in mineral nutrients and organic matter, and these make it a suitable habitat for microorganisms which was ascertained by their high enzymatic activities in this study. Due to this nutrient richness of termite mound soil, small-scale farmers can improve the soil condition of their farmland by using termite mound soil as almost no cost organic amendments. Our study shows the improved physico chemical condition of the termite mound soil compared to its surrounding soils. There is a huge scope to further study the termite mound soils in terms of their nutrient supplying power through pot culture experiments and develop effective recommendations.

References

Adam, G. & Duncan, H. (2001). Development of a sensitive and rapid method for the measurement of total microbial activity using fluorescein diacetate (FDA) in a range of soils. *Soil Biol. and Biochem.***33**(7-8):943-951

Adekayode, F.O. & Agunkoya, M.O. (2009). Comparative study of clay and organic matter content of termite mounds and the surrounding soils. *African Crop Science Conference Proceedings.* **9**: 379-384.

Arshad, M.A. (1982). Influence of the termite *Macrotermes michaelseni* (Sjöst) on soil fertilityand vegetation in a semi-arid savannah ecosystem. *Agro-Ecosystems.* **8**: 47–58.

# Avitabile, S.C., Nimmo, D.G., Bennett, A.F. & Clarke, M.F. (2015). Termites are resistant to the effects of fire at multiple spatial scales. *PLoS ONE*. 10(11):1-18.

Baig, M.M., Pandiaraj, T., Rout, A.K. Manjappa, Prabhu, D.I.G., Sinku; Chandrika, Singh, G.P. & Sinha, A.K. (2018). Evaluation of nutrient status in termite mounds and adjacent soils associated with tasar sericulture ecosystem. *J. of Ent. and Zool. Studies*, **6**(5): 206-210.

Baruah, T.C. & Barthakur, H.P. (1997). A Text Book of Soil analysis. Vikas PublishingHouse Pvt. Ltd., New Delhi, pp, 94-103.

Blake, G.R. & Hartge, K.H. (1986). Bulk density. *Methods of Soil Analysis: Part, 1.* pp.363-375.

Casida, L., Klein, D. & Santoro, T. (1964). Soil Dehydrogenase Activity. *Soil Sci*. **98** : 371-376.

Dalal, R.C. & Moloney, D. (2000). Sustainability indicators of soil health and biodiversity. In: *Management for Sustainable Ecosystems, Centre for Conservation*. Hale, P.; Petrie, A.; Moloney, D. and Sattler, P. (Eds.).

Dangerfield, J.M., Mccarthy, T.S. & Ellery, W.N. (1998). The mound-building termite Macrotermes michaelseni as an ecosystem engineer*. J. of Trop. Ecol*. **14**: 507-520.

Deke, E.L., Adugna,W.M. & Fite, A.M. (2016). Soil physic- chemical properties in termite mounds and adjacent control soil in Miyo and Yabello districts of Borana Zone, Southern Ethiopia. *American J. of Agri. and Forestry.***4**(4): 69-74.

de Lima, S.S., Pereira, M.G., Pereira, R.N., de Pontes, R.M. & Rossi, C.Q. (2018). Termite Mounds Effects on Soil Properties in the Atlantic Forest Biome. *Revista Brasiliera de Ciencia do Solo*. **42**: 1-14.

Dhembare, A.J. (2013). Physico-chemical properties of termite mound soil. *Arch. Appl. Sci. Res.***5**(6):123-126.

Donovan, S.E., Eggleton, P. & Bignell D.E. (2001). Gut content analysis and a new feeding group classification of termites. *Ecol. Ento*. **26**: 356-366.

Ekundayo, E.O. & Aghatise, V.O. (1996). Soil properties of termite mounds under different land use types in a typic Paleudult of Mid-Western Nigeria. *Environ. Monitoring and Assess.* **45**:1-7.

Eneji, I. S., Sha’Ato, R. & Ejembi, S. E. (2015). Comparative Analysis of Termiteria and Surrounding Soil Properties in the University of Agriculture, Makurdi, Nigeria.*Chem. Search J.***6**(1): 57-61.

Ensminger, L.E. (1954). Some factors affecting the adsorption of sulfate by Alabama soils. *Soil Sci. Soc. America J.* **18**(3):259-264.

Holt, J.A. & Lepage, M. (2000). Termites and Soil Properties. In: Abe, T.; Bignell, D.E. and Higashi, M. (Eds.). Termites: evolution, Sociality, Symbioses, Ecology. *Springer, Dordecht.*

ISSS (International Society of Soil Science) (1929). Minutes of the First Commission Meetings. International Congress of Soil Science, Washington 1927.

# Jackson, M. L. (1973). *Soil chemical analysis.* Prentice Hall of India pvt. Ltd; New Delhi.

Jouquet, P., Traoré, S., Choosai, Ch., Hartmann, Ch. & Bignell, D. (2011). Influence of termites on ecosystem functioning, Ecosystem services provided by termites. *European J. of Soil Biol*. **47**: 215-222.

Kooyman, C. & Onck, R.F.M. (1987). The interaction between termite activity, agricultural practices and soil characteristics in Kisil District. Kenya. *Agricultural University, Wageningen Papers,* **87**(3).

Krohmer, J. (2004). Umwetwahmehmung und – Klassifikation bei Fulbegruppen in Verschiedenen Naturraumen Burkin Faso’s und Benin’s. Ph.D. Thesis. Johann-Wolfgang-Goe the –universitat, Frankfurt.

Kumar, P.P., Tilak, M., Sivakumar, K. & Saranya, K. (2018) Studies on the assessment of major nutrients and microbial population of termite mound soil. *Intern. J. of Forestry and Crop Improv.* **9**(1): 13-17.

Leonard, J. & Rajot, J.L. (2001). Influence of termites on runoff and infiltration: quantification and analysis. *Geoderma*. **104**:17-40.

Lopez-Hernandez, D., Brossard, M., Fardeau, J. C. & Lepage, M. (2006). Effect of different termite feeding groups on P sorption and P availability in African and south American savannas. *Biol. Fert. Soils*.**42** (3): 207-214.

Ohkuma, M. (2003). Termite symbiotic systems: efficient bio-recycling of lignocellulose. *Appl. and Environ. Microbiol.***61**:1-9.

Rajagopal, D. (1983). Effect of termite mound soil on plant growth.*Trop. Pest Management*.**29**(2): 194-195.

Rowland, C., Brauman, A., Labatt, M. & Lepage, M. (1993). Nutritional factors affecting methane emission from termite. *Chemosphere*. **26** (1-4):
617-622.

# Rückamp, D., Amelung, W., Borma, L.S., Naval, L.P. & Martius, C.(2009). Carbon and nutrient leaching from termite mounds inhabited by primary and secondary termites. *Appl. Soil Ecol*. 43:159-162.

Sarcinelli, T.S. & Schaefer, C.E.G.R*.*(2009)*.* Chemical, physical and micromorphological properties of termite mounds and adjacent soils along a toposequence in Zona da Mata, Minas Zerais State, Brazil. *Catena*.**76**: 107-113.

Sarcinelli, T.S., Schaefer, C.E.G.R., Lynch, L.S., Arato, H.D., Viana, J.H.M., Albuquerque, Filho, M.R. & Gonçalves, T.T. (2009). Chemical, physical and micromorphological properties of termite mounds and adjacent soils along a toposequence in Zona da Mata, Minas Gerais State, Brazil. *Catena*. **76**:107-13.

Sarcinelli, T.S., Schaefer, C.E.G.R., Fernandes Filho, E.I., Mafia, R.G. & Neri, A.V. (2013). Soil modification by termites in a sandy-soil vegetation in the Brazilian Atlantic rain forest. *J. Trop. Ecol., Cambridge*. 29(5): 439-448

Shaefer, C.E. (2001). Brazilian latosols and their B horizon microstructure as long-term biotic constructs. *Australian J. of Soil Res.***39**: 909-926.

Sileshi, G.W., Arshad, M.A., Konaté, S. & Nkunika, P.O.Y. (2010). Termite-inducedheterogeneity in African savanna vegetation : mechanisms and patterns: termite-induced heterogeneity in African savanna vegetation. *J. Veg. Sci*. **21**: 923-937.

Subbiah, B.V. & Asija, G.L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.* **25**:259-260.

Subi, S. & Merline Sheela, A. (2020). Review on Termite Mound Soil Characteristics and Agricultural Importance. *J. Agri. and Ecol. Res Int.* **21**(7): 1-12.

Traore, S., Bottinelli, N., Aroui, H., Harit, A. & Jouquet, P. (2019) Termite mounds impact soil hydrostructural properties in southern Indian tropical forests. *Pedobiol.***74**: 1-6.

Vats, R. & Aggarwal, S. (2011). Impact of termite activity and its effect on soil composition. *Tanzania J. of Natural and Appl. Sci.* (TaJONAS). **2**(2): 399-404.

Waller, D.A. & la Fage, J.P. (1987). Nutritional ecology of termites. In: *The nutritional Ecology of Insects, Mites, and Spiders.* Slanky, Jr, F. and Rodriguez, J. G. (Eds.) John Wiley and Sons, New York.

Walkley, A. & Black, I.A. (1934). An examination of the digestion method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.***37**:29-33.