



Harnessing the Untapped Potential of Termite Mound Soil for the Improvement of the Growth of Sorghum (*Sorghum bicolor* [L.] Moench)

Aiki, I.P.,^{1*} Akogwu, S.A.,¹ Shindi, H.A.² and Aati, R.³

¹Department of Biological Science, Federal University Gashua, P.M.B 1005 Gashua, Yobe state, Nigeria.

² Department of Biological Science, Federal University of Agriculture P.M.B 28, Zuru, Kebbi State, Nigeria.

³ Department of Sciences, Kebbi State Polytechnic, Dakingari P.M.B 1158, Kebbi State, Nigeria.

Abstract

Recently the use of termite mound soil as amendments has gained more acceptance due to its availability and affordability. The aim of the study was to determine which layer of the termite mound soil contains most of the nutrients by evaluating the chemical compositions of the soil found at different layers of the mound (outer, inner, whole and surrounding). The study further aimed to use the different layers as soil amendments in the growth of sorghum to ascertain which of the layers does better in the growth of the plant. For a six weeks period, each week the length of the roots, stem lengths, leave lengths, whole plants and the wet weight of the plants were measured to determine the efficacy of the different layers of the termite mound soil on plant growth. Though there's no significant difference on the root lengths, stem lengths, leave lengths and whole plant lengths and also the wet weights of the grown plants using different layers of the termite mound soils. The result also showed some differences in the compositions of the soils analyzed from the termite mounds, the differences might be associated with the nature of the soil around the garden and the activities taking place within the mound which brings about soil improvement. From the results obtained, resource-poor farmers could use termite mounds as soil amendments. In addition, the chemical analysis of the mound soil revealed the presence of some macronutrients that could be harnessed for plant growth.

Keywords: Amendments; Macronutrient; Termite mound; Decomposition; Drought-prone; Redistribution.

INTRODUCTION

Termites play an important role in the ecosystem, most especially in the decomposition of organic materials (Sugimoto et al., 2000, Abe et al., 2000), provision of food and feed (Van Huis, 2013; Vasconcellos et al., 2015; Erpenbach and Wittig, 2016) in geological survey –(Petts et al., 2009, Affam and Arhin, 2004) and as soil amendments in

nutrient deficient soils to improve plant productivity (Chisanga et al., 2020; Adebajo et al., 2021; Tilahun et al., 2021). Shortage of farm lands due to natural and anthropogenic factors are among the challenges faced by farmers (Ajao and Anurigwo, 2002; Khan and Ghouri, 2011), where the lands are available they have been over stretched due to continuous cropping which made the soils to become deficient in nutrient (Chianu et al., 2011; Umar et al., 2013, .

*Correspondence email:-

istifanusaiki@fugashua.edu.ng;

istifanus.aiki@tuks.co.za

ORCID NUMBER: 0000-0002-6981-6919

A review was carried out on the characteristics, microbial diversity and organic matter degrading enzymes in termite mound soil and the characteristics of compost amended with termite mound soil and its effect on crop productivity. Majority of the findings showed that termites mound soils are a better option as soil amendments in crop production (Apori et al., 2020; Subi and Sheela, 2020). Termites enhance the fertility of the soil through their activities and also play a key role in energy transfer via trophic interactions at various levels which make them to be major players in the ecosystem (Khan and Ahmad, 2018). Excavation and transportation of soil during mound building by termites helps in moving both macro and micro nutrients from different locations to be concentrated within the mound and also around the mound environment due to washing away of the mound soil by rain water (Chisanga *et al.*, 2020).

Gentili et al. (2018) in their study investigated the effects of soil pH and their results showed that plants grown on soil with pH5 and pH6 are better when compared with those grown on soil with pH7 using the following parameters heights, dry weight, developments of leaves and production of flowers and pollen. In a related study, Li *et al.* (2017) reiterate that termites desire an acidic habitat and that their activities promote the pH of termitarian soil compared with neighbouring soils. Availability of Phosphorus (P) is vital for regulating crop growth and development, similarly it also plays a fundamental role in the health of the plants (Wynngaard. *et al.*, 2016). During photosynthesis P is considered an essential component of Adenosine Triphosphates (ATP). ATP plays an essential role in the formation of seeds and maturity of the plants from the seedlings to harvest making P an indispensable macro nutrient of plant (Khan *et al.*, 2023).

Nitrogen (N) is among the macro-nutrients found in termite mound soil which came about mostly due to the use of faecal materials to build gallery walls and it's needed by plants for a healthy growth and provision of energy to plants tissues. It is also one of the major constituents in protein synthesis, and it's usually found in nature incorporated in some compounds (López-Hernández, 2001). Another way in which plants acquire N is through a process whereby a leguminous crops acquired N gas from the atmosphere by forming nodules with soil-inhabiting bacteria called rhizobia (López-Hernández, 2001; Fairhurst, 2012). Nieves-Cordones et al. (2016) reported that Sodium plays a role in the removal of both inorganic and organic anions and macromolecules, pH homeostasis, control of membrane electrical potential amongst others. While Zörb et al. (2014) reported some of the symptoms of potassium deficiencies in plants to include brown spots on leaf surface or edge of the leaves and chlorosis at the tip of the older leaves. Smil (1999) reported that symptoms could be remedied by applying sufficient potassium fertilizers to the farmland

Obi et al. (2019) revealed that there is no difference in termite mounds soil and that of the surface soil in available phosphorus, exchangeable sodium and potassium, effective cation exchange capacity, fine sand and silt where they suggest that the similarities were as a result of uniform distribution through erosion and redistribution of the mound material around the mound that were studied. Similarly, Tilahun et al. (2021) reported the availability of nutrients in termite mound soils and its efficacy as soil amendment.

The research was conducted to determine which layer of the termite mound soil has higher nutrient.

MATERIALS AND METHODS

Study area

The study was carried out at the experimental

farm in the biological garden of the Federal University, Gashua Yobe State Northeastern Nigeria. Gashua is located within the sub-Saharan climatic zone between latitude 12°52'5"N and longitude 11°2'47"E with an average elevation of 299 m. The hottest months are March and April with temperatures ranging from 38 to 40° C. The rainy season start from June to September in which the temperatures fall between 23 to 28°C, with rainfall of about 500 to 1000mm.

Experimental set-up and data Collection

Four triplicate of 1 × 2 meters plots (A-D) were prepared for planting of sorghum seeds, the seeds were bought from Gashua cereal market, local variety of sorghum known as “Kaura” was used for the research, “Kaura” is a variety of sorghum that is most preferred in Northern Nigeria which is well adapted to the region and cultivated for food (Ahmad et.al., 2022). Each plot was prepared and treated/mixed with different layers of termite soils. The first batch (A1, A2 and A3) were taken as the control using soils from the surrounding environments (about 2m from the mound), the second batch (B1, B2 and B3) were mixed with about 50kg of outer layer (depth of 0-30cm depending on the height of the mound) of the termite mound soil each, the third (C1, C2 and C3) was mixed with about 50kg of inner layer (depth beyond 30cm to the fungus garden at the center of the mound) of termite mound soil each and the fourth (D1, D2 and D3) about 50kg of the complete termite mound soil were also used in each of the plots. Approximately, 36-40-inch row spacing was used throughout the experiment. The plants were monitored for six weeks. In each week the roots length, stems height, leaves length and the whole plants were measured, the wet weight of the plants were also measured for the period of the six weeks.

Soil analysis and Insect Identification

The termite mound soil used for the experiment

were obtained from the experimental farm of the Federal University Gashua, Yobe State, Nigeria while the termites were identified at Ahmadu Bello University, Zaria (ABU) Nigeria. The soil analysis was carried out at the analytical Chemistry laboratory of the Department of Chemistry, Faculty of Science, Yobe State University, Damaturu. The soils were analyzed in accordance with the methods established by van Reeuwijk (1998).

Statistical Analysis

A one-way analysis of variance (ANOVA) was carried out to ascertain the differences in the soil chemical composition of the different layers of the termite mound soil (complete mound, inner layer, outer layer and surrounding soil). Plants grown on the plots treated with the different layers of the termite mound soils and the untreated plots (control soil) were also analyzed to ascertain their differences using the following variables: lengths of roots, length of stems, length of whole plants and wet weight of the whole plant. All statistical analyses were carried out using R (R Core Team 2018) with alpha level set at 0.05.

RESULTS

Soil analysis and Insects identification

The termites within the mounds were identified as *Macrotermes* and *Odontotermes* species, mound soils belonging to the identified species were used to carry out the research. The result of the soil analysis of the different layers of the termite mound soil and the control soil is presented in Table 1. The composition of the inner layer of the mound soil was higher in Cation Exchange Capacity (CEC), Electrical Conductivity (EC), Organic Carbon (OC), Nitrogen (N), clay and silt while control soil showed higher pH and sand when compared to others. Potassium (K) and Sodium (Na) have higher values in complete mound soil. The analysis of variance (ANOVA) of the termite mound soil and that of the surrounding soil showed a significant difference in their

pH ($F = 9.463$, $P = 0.0108$), Organic Carbon ($F = 9.297$, $P = 0.0113$), Clay ($F = 35.58$, $P = 0.000323$) and Sand ($F = 20.02$, $P = 0.00158$) while Electrical Conductivity ($F = 2.372$, $P = 0.169$), Nitrogen ($F = 2.237$, $P = 0.184$), Potassium ($F = 0.605$, $P = 0.636$), Sodium ($F = 0.75$, $P = 0.561$), CEC ($F = 0.135$, $P = 0.935$) and Silt ($F = 0.839$, $P = 0.52$) are not significantly different. The composition of (a) Clay, Silt and Sand, (b) Nitrogen, Potassium, Sodium and Organic Carbon, (c) pH, (d) CEC and (e) EC of soil samples of surrounding soil (control), outer, inner and complete mound soil is compared in Figure 1.

Analysis of plants grown on different layers of the termite mound soils

Table 2 presents the roots length, stem length, leave length and whole plant length as well as the wet weight of the whole plant. The plots treated with complete mound soils showed the maximum average for all the measured variables. All the measured variables: root length, stem length, leave length, the length of the whole plants and wet weights of the grown plants using the different layers of the termite mound soil and the surrounding soil did not show any significant difference ($F = 0.734$, $P = 0.544$), ($F = 0.966$, $P = 0.428$), ($F = 0.937$, $P = 0.441$), ($F = 1.202$, $P = 0.334$), ($F = 0.844$, $P = 0.486$) respectively.

Table 1. Soil analysis of complete, control (surrounding soil), inner and outer part of termite mound soil

Sample	pH	CEC	EC (mS/cm)	Percent (%)						
				Organic Carbon	Nitrogen (N)	Potassium (K)	Sodium (Na)	Clay	Silt	Sand
Complete	5.40 ± 0.23	0.0013 ± 0.00	599.26 ± 266.0	1.75 ± 0.41	0.53 ± 0.15	0.29 ± 0.46	0.068 ± 0.11	46.89 ± 6.35	4.20 ± 2.98	49.48 ± 9.35
	6.82 ± 0.42	0.0000 ± 0.00	295.10 ± 22.85	1.06 ± 0.03	0.29 ± 0.01	0.02 ± 0.01	0.012 ± 0.00	26.81 ± 0.64	5.36 ± 0.21	67.11 ± 0.07
Inner	5.12 ± 0.34	0.0020 ± 0.00	878.58 ± 258.20	2.74 ± 0.46	0.55 ± 0.10	0.05 ± 0.06	0.005 ± 0.00	64.83 ± 3.06	6.55 ± 1.82	26.02 ± 3.59
	5.73 ± 0.28	0.0013 ± 0.00	415.68 ± 207.03	1.13 ± 0.33	0.39 ± 0.08	0.02 ± 0.02	0.003 ± 0.00	34.37 ± 1.42	3.24 ± 3.00	60.35 ± 2.30

Cation Exchange Capacity (CEC), Electrical Conductivity (EC) and standard deviation (±)

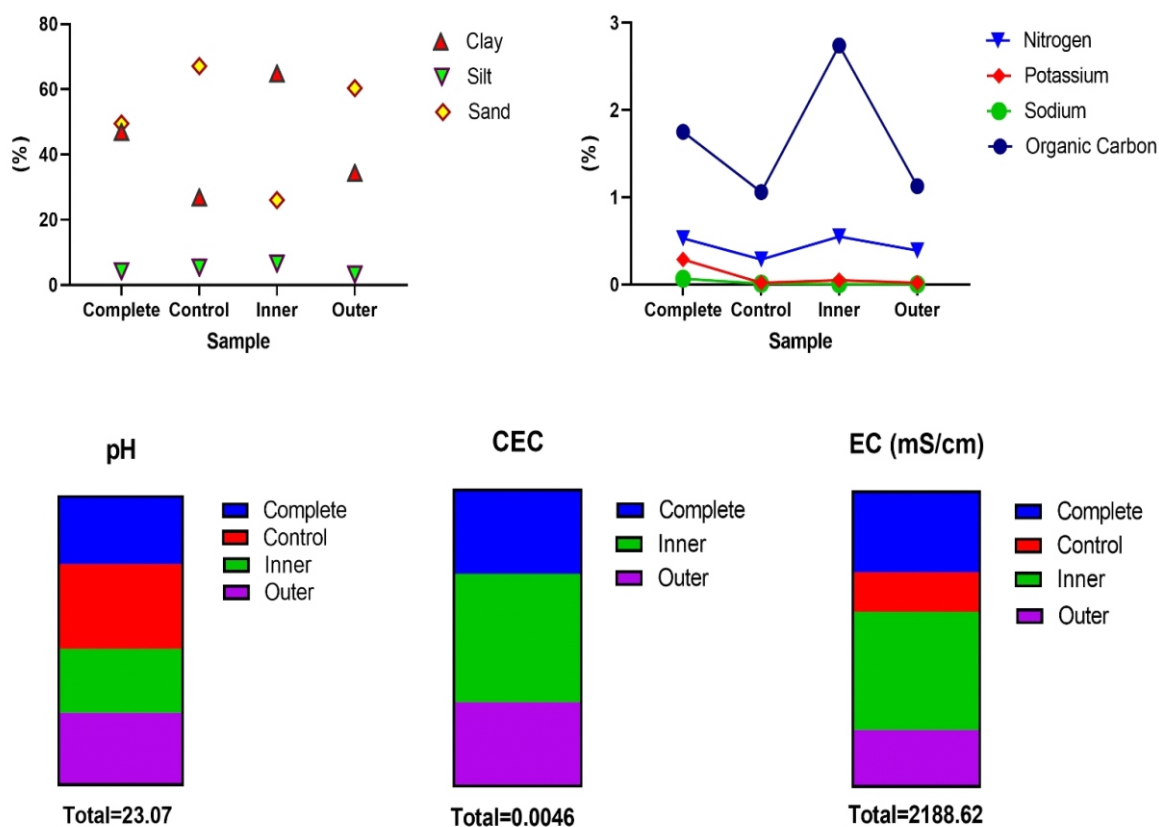


Figure 1. Average composition of (a) Clay, Silt and Sand, (b) Nitrogen, Potassium, Sodium and Organic Carbon, (c) PH, (d) Cation Exchange Capacity (CEC) and (e) Electrical Conductivity (EC) of soil samples

Table 2. Length of roots, stems, leaves, whole (complete) and wet weight of plants grown on different layers of termite mounds and the surrounding (control) soils.

Sample	Root (cm)	Stem (cm)	Leaves (cm)	Complete plant (cm)	Wet Weight (g)
Control	...	7.25 ± 4.61	20.12 ± 14.98	30.24 ± 15.39	1.70 ± 3.15
Outer layer	7.87 ± 5.20	7.38 ± 5.76	21.16 ± 16.32	36.39 ± 26.68	3.65 ± 7.53
Inner layer	8.13 ± 2.58	7.49 ± 3.73	21.83 ± 12.21	37.47 ± 17.38	1.60 ± 2.34
Complete mound	10.32 ± 7.48	12.15 ± 8.59	33.88 ± 20.71	56.35 ± 35.93	7.54 ± 12.12

Standard deviation (±)

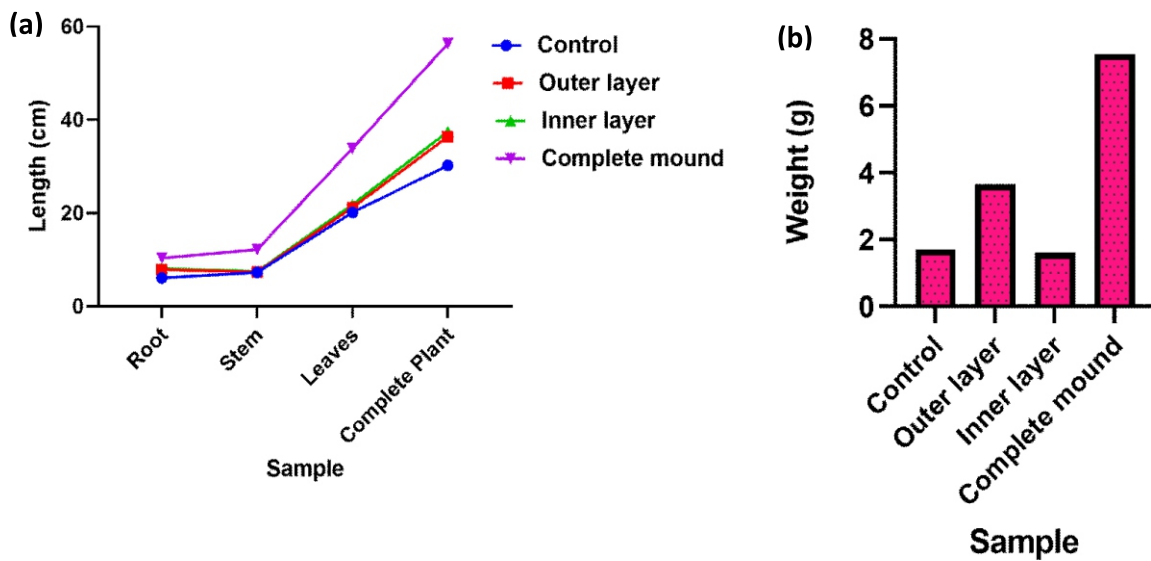


Figure 2 (a) Length of the roots, stems, leaves and the whole (complete) plants (Sorghum) grown using different layers (outer, inner and complete) of the termite mound soil and the surrounding (control), (b) Wet weight of the whole plant grown on the different layers of the termite mounds.

DISCUSSION

The result of the soil analysis showed a significant difference in the composition of pH, organic carbon (OC), clay and sand in the termite mound soil and that of the surrounding soil while electrical conductivity (EC), Nitrogen (N), Potassium (K), Sodium (Na), Cation Exchange Capacity (CEC) and Silt did not show any significant difference in their composition. After using the different layers (outer, inner, whole and surrounding) of the mound soil to grow sorghum (cereal crop), the result showed no significant difference in the root length, stem length, leave length, whole plants length and wet weight of the whole plant. Determining the average of the sorghum grown on plots treated with different layers of the termite mound soil, complete termite mound soil plot presents maximum length in all the measured parameters of the grown plant. Similarly, the measured values of the wet weight of the complete plants grown on plot treated with complete termite mound soil were better than the others. Though there were

no significant difference on the plant grown on the different layers of the termite mound soil used, this might also be as a result of the soils found in the environment and the species of termite that are involved in the mound building activities. Aside the type of food eaten by the termites the nature of the soils found around the area where the termites build their mound contribute to a greater extend in determining the fertility of the termite mound soil (Bonanomi and Mazzoleni, 2005, Passioura, 2002). Homogenization of the constituent of the mound materials and redistribution to the surrounding environments through washing away of the mound soils also plays a part in the uniform distribution of materials around the mound which might also affect the growth of the plant (Obi et al., 2019). Termites mound soil can serve as amendments most especially to subsistence farmers who could not afford fertilizers to supplement the nutrient deficient soils of their farm lands (Yanggen et al., 1998; Chisanga et al., 2020). Eggleton et al. (1995) considered *Macrotermes* and *Odontotermes*

among the more resilient termite species which can survive even in a disturbed habitat. The mode of feeding and the availability of the feeding materials of the aforementioned help them to survive even in an environment that other species could not survive. Findings revealed how beneficial termite mound can be, considering the nutritional content of the soils when used as amendment for crop production. The nutritional value of the mound soils is dependent on the type of species of termites that build them which is directly related to the feeding material of the termite (Donovan et al., 2001; Desouza and Canello, 2011).

The results of the study showed more pH in the control soil than in the mound soils suggesting that the soil found in the area are slightly acidic. Previous work showed that the pH in the different layers of the mound soils are within the acceptable limit for healthy plant growth (Chapoto et al., 2016; Gentili et al., 2018; Chisanga et al., 2020,). The result also showed that complete mound provides sufficient Potassium (K) which is above the critical level for a healthy soil and consequently good for plant production. Fairhurst, (2012) opined that termite mound soil serve as a reservoir for K and can be a good amendment to improve soil deficient in K which will invariably improve the productivity of the soil. Termites carefully select and work on the soil particles that are used in mound constructions (Ekundayo and Orhue, 2002). Selecting soil particles in the mound constructions can also be observed in the percentage composition of clay, silt and sand across the different layers of the termite mounds soils and that of the surrounding soils (Robert et al., 2007). The size of the soil particles used in mound construction is sometimes directly related to the size of the worker termites and that also due to their mandible size used in picking the soil particles.

Texturally the soil of the studied environments followed the same pattern with almost similar composition of sand > clay > silt in complete mound, control soil and outer soils with the exception of inner layer which presents a different formation of clay > sand > silt. Fairhurst (2012) referred to soil with large proportion of sand as light- or coarse-textured soils and considered them to be drought-prone than soils containing more clay. Soil texture is influential in determining the direction of water flow in the soil which by implication determines the type of crop to be grown.

Termite helps in nutrient recycling which usually takes place within their mound and which also depends on the type of food they consumed. Most of the unconsumed food items are left to decompose within the mound in addition to the termites feces which helps in increasing the nutritional content of the termite mound soils either directly or indirectly as amendment to plants in the fields when properly used (Peterson, 2010; Enagbonma and Babalola, 2019). Smil (1999) suggest that complete recycling of plant residues which termites actively participate and their eventual mineralization would supply some percentages of N, P, and K applied in inorganic fertilizers. The current study showed termite mounds to contain some nutrient than the surrounding soil which can support plant growths and increase the nutritional content of the soil thereby increasing the soil productivity in the face of nutrient deficiencies faced by resource poor farmers who could not afford the inorganic fertilizer to improve their crop production.

CONCLUSION

Although there was no significant difference in the length of the roots, stem length, leave length and whole plant as well as wet weight of sorghum plants using different layers of the termite mound soils, the result showed some

variations in the compositions of the soil analyzed from the termite mound soils. The difference might be associated to the nature of the soil around the garden and the activities taking place within the mound which brings about soil improvement. The result revealed an increased in crop grown on a plot treated with whole termite mounds soil rather than a particular layer of the termite mound. Considering how tedious and time consuming it could be to sort the different layers of the termite mound for soil amendment, the result support the use of the whole mound as amendment which should be better in terms of nutritional content and time management. In addition, chemical analysis of the mound soils revealed the presence of some macronutrients that can be harnessed for plant growth. It is recommended that resource poor farmers can use termite mound soil as soil amendments. Considering the high cost of mineral fertilizers, termite mound soil presents a better and cheaper substitute for farmers to improve plant productivity.

Mounds of other species aside the *Macrotermes* and *Odontotermes* should also be used as soil amendments to ascertain if there exist any difference in plant growth and development. Similarly, other parameters such as dry weight of the plants, quality of the flowers and seeds development should be considered, and the duration of the experiment should be increased to the stage of seed maturity of the plants so as to assess the difference. In order to harness the best of the termite mounds as soil amendment, we hereby recommend the use of the whole termite mound soils instead of some layers of the termite mound as soil amendment.

ACKNOWLEDGMENTS

Our appreciation goes to the entire academic staff of the Department of Biological Science of Federal University Gashua for their

constructive criticism in the course of this work. We also appreciate the effort of the laboratory Scientists of the Department for their contributions. We acknowledged M. Alkali of the Department of Chemistry, Yobe State University, Damaturu for helping with the laboratory analysis.

REFERENCES

- Abe, T., Bignell, D. E. and Higashi, M. (2000).** *Termites : Evolution, Sociality, Symbioses, Ecology*, Dordrecht Kluwer Academic Publishers, 1-466.
- Adebajo, S. O., Akintokun, P. O., Ezaka, E., Ojo, A. E., Olannye, D. U. and Ayodeji, O. D. (2021).** Use of termitarium soil as a viable source for biofertilizer and biocontrol. *Bulletin of the National Research Centre*, 45(100): 1-8.
- Affam, M. and Arhin, E. (2004).** Termite Mounds supplementary geochemical gold sampling medium in complex regolith terrains. *Ghana Mining Journal*, 8, 1-7.
- Ajao, E., and Anurigwo, S. (2002).** Land-based sources of pollution in the Niger Delta, Nigeria. *Ambio*, 31(5):442-445.
- Apori, S.O., Murongo, M., Hanyabui, E., Atiah, K. and Byalebeka, J.(2020).** Potential of termite mounds and its surrounding soils as soil amendments in smallholder farms in central Uganda. *BMC Res Notes* 13 (397): 1-6. <https://doi.org/10.1186/s13104-020-05236-6>
- Bonanomi, G. and Mazzoleni, S. (2005).** Soil history affects plant growth and competitive ability in herbaceous species. *Community Ecology*, 6 (1): 23-28.
- Chapoto, A., Chabala, L. M. and Lungu, O. N. (2016).** A Long History of low productivity in Zambia: Is it time to do away with blanket recommendations? *Zambia Social Science Journal*, 6 (2):1- 6.
- Chianu, J., Nkonya, E. M., Mairura, F., Chianu, J. and Akinnifesi, F. (2011).** Biological nitrogen fixation and socioeconomic factors for legume production in sub-Saharan Africa: a review. *Agronomy for sustainable development*, 31(1): 139-154.
- Chisanga, K., Mbega, E. R. and Ndakidemi, P. A. (2020).** Prospects of Using Termite Mound Soil Organic Amendment for Enhancing Soil Nutrition in Southern Africa. *Plants (Basel, Switzerland)*, 9 (5): 1-649.
- Desouza, O. and Canello, E. M. (2011).** Termites and Ecosystem function. *International Commission on Tropical Biology and Natural Resources*, 1-389.

- Donovan, S., Eggleton, P. and Bignell, D. (2001).** Gut content analysis and a new feeding group classification of termites. *Ecological Entomology*, 26 (4): 356-366.
- Eggleton, P., Bignell, D. E., Sands, W. A., Waite, B., Wood, T. G. and Lawton, J. H. (1995).** The Species Richness of Termites (Isoptera) Under Differing Levels of Forest Disturbance in the Mbalmayo Forest Reserve, Southern Cameroon. *Journal of Tropical Ecology*, 11(1): 85-98.
- Ekundayo, E. and Orhue, E. (2002).** Properties of termite mounds soil in the Niger Delta region of Southern Nigeria. *J. Sci. Technol. Res.*, 14:15-21.
- Enagbonma, B. J. and Babalola, O. O. (2019).** Potentials of termite mound soil bacteria in ecosystem engineering for sustainable agriculture. *Annals of Microbiology*, 69: 211-219.
- Erpenbach, A. and Wittig, R. (2016).** Termites and savannas: an overview on history and recent scientific progress with particular respect to West Africa and to the genus *Macrotermes*. *Flora et Vegetatio Sudano-Sambesica*, 19: 35-51.
- Fairhurst, T. (2012).** Handbook for integrated soil fertility management, CTA/CABI.
- Gentili, R., Ambrosini, R., Montagnani, C., Caronni, S. and Citterio, S. (2018).** Effect of Soil pH on the Growth, Reproductive Investment and Pollen Allergenicity of *Ambrosia artemisiifolia* L. *Frontiers in Plant Science*, 9: 1-1335.
- Khan F., Siddique A. B., Shabala S., Zhou M. and Zhao C. (2023).** Phosphorus Plays Key Roles in Regulating Plants' Physiological Responses to Abiotic Stresses. *Plants (Basel)*. 12 (15):1-2861. <https://doi.org/10.3390/plants12152861>. PMID: 37571014; PMCID: PMC10421280.
- Khan, M. A. and Ahmad, W. (2018).** Termites and sustainable management. Economic losses and management. Cham, Switzerland: Springer, 2 (1): 1-324.
- Khan, M. A. and Ghouri, A. M. (2011).** Environmental pollution: its effects on life and its remedies. *Researcher World: Journal of Arts, Science & Commerce*, 2 (2): 276-285.
- Li, Y., Dong Z. Y., Pan, Z., Pan C. H. and Chen L. H. (2017).** Effects of Termites on Soil pH and Its Application for Termite Control in Zhejiang Province, China. *Sociobiology*. 64 (3):317-326. <https://doi.org/10.13102/sociobiology.v64i3.1674>
- López-Hernández (2001).** Nutrient dynamics (C, N and P) in termite mounds of *Nasutitermes ephratae* from savannas of the Orinoco Llanos (Venezuela), *Soil Biology and Biochemistry*, 33(6): 747-753. [https://doi.org/10.1016/S0038-0717\(00\)00220-0](https://doi.org/10.1016/S0038-0717(00)00220-0)
- Muhammad, A.Y., Hussein, S., Baloua N., Chris O.O. and Gideon D. A. (2022).** Sorghum production in Nigeria: opportunities, constraints, and recommendations, *Acta Agriculturae Scandinavica, Section B Soil & Plant Science*, 72 (1):660-672, DOI:
- Nieves-Cordones, M., Shiblawi, A., Razzaq, F. and Sentenac, H. (2016).** Roles and transport of sodium and potassium in plants. The alkali metal ions: Their role for life. Springer, 16: 291-324.
- Obi, J., Ibia, T. and Isaiah, A. (2019).** Termite activities and surface characteristics of coastal plain sands. *Agro-Science*, 18(1), 56-66.
- Passioura, J. (2002).** Soil conditions and plant growth. *Plant, Cell & Environment*, 25 (2): 311-318.
- Peterson, C. (2010).** Review of termite forest ecology and opportunities to investigate the relationship of termites to fire. *Sociobiology*, 56(2):313-352.
- Petts, A. E., Hill, S. M. and Worrall, L. (2009).** Termite species variations and their importance for termitaria biogeochemistry: towards a robust media approach for mineral exploration. *Geochemistry: Exploration, Environment, Analysis*, 9(3): 257-266.
- R Core Team (2018)** R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna. <https://www.R-project.org>
- Robert, O. E., Frank, U. O. and Agbonsalo, O. U. (2007).** Influence of activities of termites on some physical and chemical properties of soils under different land use patterns: a review. *Int. J. Soil Sci*, 2 (1): 1-14.
- Smil, V. (1999).** Crop Residues: Agriculture's Largest Harvest: Crop residues incorporate more than half of the world's agricultural phytomass. *Bioscience*, 49(4), 299-308.
- Subi, S. and Sheela, A. M. (2020).** Review on termite mound soil characteristics and agricultural importance. *J Agric Ecol Res Intl*, 21(7): 1-12.
- Sugimoto, A., Bignell, D. E., and Macdonald, J. A. (2000).** Global impact of termites on the carbon cycle and atmospheric trace gases. *Termites: evolution, sociality, symbioses, ecology*. Springer, 409-435.
- Tilahun, A., Cornelis, W., Sleutel, S., Nigussie, A., Dume, B. and Van Ranst, E. (2021).** The Potential of Termite Mound Spreading for Soil Fertility Management under Low Input Subsistence Agriculture.

- Agriculture, 11(10):1002.
- Umar, B. B., Aune, J. B., and Lungu, O. I. (2013).** Effects of *Faidherbia albida* on the fertility of soil in smallholder conservation agriculture systems in eastern and southern Zambia. *African Journal of Agricultural Research*, 8 (2): 173-183.
- Van Huis, A. (2013).** Potential of insects as food and feed in assuring food security. *Annual review of entomology*, 58, 563-583, doi: 10.1146/annurev-ento-120811-153704.
- Van Reeuwijk, L. (1998).** Guidelines for quality management in soil and plant laboratories, *Food & Agriculture Org*, 74:1-134.
- Vasconcellos, A., Policarpo, I. S. and Alves, R. (2015).** Edible and medicinal termites: a global overview. *Journal of ethnobiology and ethnomedicine*, 11, 29-29.
- Wyngaard, N., Cabrera, M. L., Jarosch, K. A. and Bünemann, E. K. (2016).** Phosphorus in the coarse soil fraction is related to soil organic phosphorus mineralization measured by isotopic dilution. *Soil Biology and Biochemistry*, 96: 107-118.
- Yanggen, D., Kelly, V. A., Reardon, T., and Naseem, A. (1998).** Incentives for fertilizer use in sub-Saharan Africa: A review of empirical evidence on fertilizer response and profitability, 70:1-129.
- Zörb, C., Senbayram, M., and Peiter, E. (2014).** Potassium in agriculture status and perspectives. *Journal of plant physiology*, 171 (9): 656-669.

