Global Journal of Earth and Environmental Science
Volume 9(3), pages 82-86, October 2024
Article Number: 04EF738C1
ISSN: 2636-6002
https://doi.org/10.31248/GJEES2024.158
https://integrityresjournals.org/journal/GJEES

Review Article

Effects of lithology and weathering on mineral nutrient elements uptake by plants – A review

Kabiru Usman[1]* and Rilwanu Muhammad[2]

[1]Department of Biochemistry, Federal University Gusau, Zamfara State, Nigeria.
[2]Department of Chemistry, Federal University Gusau, Zamfara State, Nigeria.

*Corresponding author. Email: kabiruusman002gmail.com/usmankabir@fugusau.edu.ng; Tel: +234(0)8065247435.

Received 15th August 2024; Accepted 20th September 2024

ABSTRACT: Mineral is an inorganic element required in minute quantity as an essential nutrient by living organisms to undertake functions necessary to sustain life. Minerals include iron, potassium, nitrogen, calcium, phosphorus, sodium, and sulfur. The formation of soils during weathering processes contributes greatly to the biogeochemical cycling of these elements. Sedimentary rocks have been the most important soil parent materials and thus, the accessibility of mineral nutrient elements to plants is dependent on the ease of weathering of rocks as well as their compositions. The process of weathering is in turn influenced by lithology which makes available new mineral elements of different reactivity for weathering reactions. Natural sources such as soil and water are the two most important sources of mineral nutrient elements for plants. The ability of soil to supply the plants with important nutrient mineral elements as well as the production of quality agricultural crop produce in a given community is all linked to the parent material a soil originated from. In this review, the functions of some mineral elements, accessibility and bioavailability of mineral nutrient elements to plants are discussed. The distribution and influence of lithology and parent materials on crop production in plants are also elucidated.

Keywords: Element, nutrient, mineral, plants, rock, soils, weathering,

INTRODUCTION

Mineral elements are a group of inorganic substances required in minute amounts but responsible for the maintenance of biochemical processes in the body. They are found in all body tissues and fluids. Minerals produce no calories but participate in many important biochemical processes in the body (Malhotra *et al.,* 2020; Ogunbode *et al.,* 2021). These inorganic elements are required by all forms of living matter for their overall normal processes of life (Ozcan, 2003; Soetan *et al*., 2010). Minerals are broadly classified into macro and micro (also called trace) elements. Examples of macro minerals are calcium, phosphorus, sodium and chloride while iron, copper, cobalt, potassium, magnesium, iodine, zinc, manganese, molybdenum, fluoride, chromium, selenium and sulfur are examples of micro-elements (Ogunbode *et al.,* 2021).

Trace elements as well as vitamins and other minerals are reported to be supplements to staple foods of wild edible and traditional vegetables (Serif *et al.,* 2018). The growth of wild food plants in natural conditions makes them easily accessible and freely harvestable for their nutritional value. They are important in households for food security as well as nutritional values in rural areas during seasonal shortages of foods (Gari, 2003). However, for plants, natural sources such as soil and water are reported to be the main sources of mineral nutrients for plants (Nganje and Adamu, 2014).

These mineral nutrients are carried through the roots to different parts of the plants. Among the minerals, trace minerals function as a useful part of pigments and enzymes. These elements include Cu, Ni, Zn, Co, and Mo. However, metals such as Cd, Pb, Hg, Cu and Se have the ability to disrupt the functions of enzymes, replace essential metals in pigment and produce reactive oxygen species as they are toxic at high concentrations (Yeboah *et al.,* 2021). Apart from natural sources, mineral nutrients are also released from human activities (anthropogenic). This review highlights the functions of some mineral elements and their accessibility and bioavailability to plants.

BIOCHEMICAL FUNCTIONS OF SOME MINERAL ELEMENTS IN PLANTS

Mineral elements are inorganic ions absorbed from the soil through the roots to different parts of plants. These elements are important for the normal growth of plants and include carbon, hydrogen and oxygen (Williams, 2020). These minerals are obtained and utilised differently in different forms. For instance, carbon is taken in the form of atmospheric carbon dioxide while hydrogen and oxygen are obtained from water. While others, such as nitrogen, sulfur, potassium, and calcium are obtained from the soil. About 50 elements are reported to be present in plants although, not all of these are essential for plants' functions. As these minerals are selectively absorbed from the soil by the roots of the plants, interestingly, the presence of certain minerals in plants can be a reflection of the compositions of the soil the plants are growing.

Minerals play different functions in plants. Among the biochemical functions that minerals play in plants is enzyme activity. Hu *et al.* (2021) reported the enzymatic activity of cobalt in plants. Cobalt has been reported to increase the activity of catalase enzymes in cotton. Cobalt also increases the activity of catalase, ascorbic oxidase, polyphenol oxidase and peroxidase in grapevines. It also increases the activity of some enzymes in tomatoes such as catalase and dehydrogenase. The ability of cobalt to enhance the drought resistance of barley, corn, oats and soybeans is also reported (Hu *et al.,* 2021).

Another important mineral for vascular plants is boron (Lewis, 2019). This mineral element functions in forming stable 6-P-gluconateborate complexes and restricts the inflow of substrate into the hexose monophosphate pathway as well as the synthesis of phenols leading to an increase in glycolysis and the synthesis of hemicelluloses and other related cell wall materials (Lewis, 2019). Other functions include potassium serving as a cofactor of enzymes of protein synthesis. Calcium plays an important role in the formation and stability of cell walls, activation as well as regulation of responses of cells to stimuli.

As these chemical elements play significant roles in the functions of plants, their deficiency presents noticeable symptoms, such as stunted growth and discolouration of leaves.

ACCESSIBILITY AND BIOAVAILABILITY OF MINERAL NUTRIENT ELEMENTS TO PLANTS

The most important soil parent materials are the sedimentary rocks and they are known to overlie most igneous formulations. They account for over 75% of the outcrops of the earth's surface (Siegel, 2002; Cox, 1995). The accessibility of mineral nutrients to plants as well as ecosystems is dependent on the ease of the weathering of rocks, their compositions and the types of nutrients, plant species and age. Toxicity of the levels of metals in soil affects soil organisms with a secondary effect on soil organic matter decomposition, mineralization of nitrogen as well as uptake which subsequently affects the yield of the crops and quality (Nganje and Adamu, 2014).

Some amounts of trace elements in the soil are accumulated as a result of either the local difference in geochemistry or anthropogenic activities. Studies have investigated the amount of trace elements in soils as well as edible plants from contaminated soils due to anthropogenic activities (Kabata-Pendias and Pendias, 2002) with little or no studies focusing on native agricultural soils. Abdullahi *et al.* (2021) also reported the source, accumulation, and health risks of heavy metals in contaminated soil. Fang *et al.* (2010) and Kwong *et al.* (2009) reported on enhanced levels of metals in soils developed over shale. The uptake of trace elements by plants is dependent on the soil as well as other important factors such as source and chemical forms of elements in soil, organic matter, pH and plant age (Nganje and Adamu, 2014).

WEATHERING AND DISTRIBUTION OF NUTRIENT MINERAL ELEMENTS IN PLANTS

Weathering is a process that involves the regulation of climate, shaping of landscapes, and derivation of the production of mineral nutrients as well as the formation of soil and its development (Chapela Lara *et al.*, 2018; Moore *et al.*, 2018). This process of soil formation releases soil mineral nutrients such as calcium, magnesium and potassium from the weathering process to drive the creation of a critical zone (Chapela Lara *et al.*, 2018). A critical zone is defined as the region from the top of the vegetation cover to the bottom of the groundwater zone (Brantley and Lebedeva, 2011).

Apart from the process of soil formation by weathering, other factors such as climate, land use, vegetation and lithology are also responsible for affecting the rate of formation of soil, production, and distribution of mineral nutrients. The process of weathering is influenced by lithology which makes available new mineral elements of different reactivity for weathering reactions. The process of weathering has also been reported to be impacted by the vegetation process. This is done by the reduction of erosion rates and subsequent formation of dense soils that ensure the blockage of bedrock from coming in contact with water, reducing weathering rates at depth (Oliva *et al.*, 2003). The biogeochemical cycling of mineral elements is greatly contributed by soil formation done during weathering reactions (Dawson *et al.,* 2020).

Depending on the environment, the distribution of mineral elements depends on but is not limited to weathering, leaching, and atmospheric deposition (Dawson *et al.,* 2020; Uhlig *et al.*, 2017; Uhlig and von Blanckenburg, 2020). The process of weathering provides the soils with minerals that are formed from sources of lithospheric origin such as rocks (Buss *et al.*, 2017; Frings and Buss, 2019). The weathering process controls the gravity as well as the distribution of nutrient inputs (Dawson *et al.*, 2020; Moore *et al.,* 2017; Uhlig *et al.*, 2017).

ROLE OF LEACHING AND WEATHERING IN THE REMOVAL OF DOMINANT MINERALS IN CARBONATE ENVIRONMENTS

Leaching is one of the processes that remove mineral nutrients released through the weathering process in environments that have slower removal of minerals through erosion than mineral dissolution thereby depriving the vegetation of required mineral elements (Dawson *et al.*, 2020). Nutrient elements such as potassium, phosphorous and calcium in these kinds of environments appear to be much more predominant near the surface than minerals such as magnesium and sodium (Dawson *et al.,* 2020) due to a process of biolifting, process that plants use to scavenge nutrients at depth and make them predominant on the surface of soils or vegetation cycling (Dawson *et al.,* 2020; Uhlig and von Blanckenburg, 2019).

The amount of soil formation as a result of weathering is dependent on the composition as well as the type of rock (Porder *et al.*, 2015). For example, carbonate soils are formed when impure carbonate bedrock that has some silicates is dissolved or when parent materials are deposed or as a result of both processes (Muhs and Budahn, 2009). However, what remains unclear is if these two sources of soil formation in carbonate environments are direct correspondents of the available mineral nutrients in soil. For instance, even though soils formed from the weathering of silicate bedrock are rich in nutrients, very thick and weathered in the granitic and andesitic watersheds in Puerto Rican rainforest, most of the mineral elements used by vegetation were deposited from atmospheric dust (Buss *et al.*, 2017).

The dominant minerals found in carbonate environments are mostly calcite and dolomite, and these minerals are weathered away quickly leaving the soil matrix enriched in soil forming aluminosilicates as well as other metal hydroxides regarded as impurities. These soils lacking quality nutrients result in a loss of biomass and vegetation cover as well as increase in susceptibility of the soils to rocky desertification. Soils have been transformed globally leading to accelerated soil degradation, anthropogenic activities such as land use and land cover change. This soil degradation or loss of nutrients has resulted in the loss of 33% of global land resources at a 0.5% annual rate (Foley *et al.*, 2005).

INFLUENCE OF LITHOLOGY AND PARENT MATERIALS ON CROP PRODUCTION BY PLANTS

Soil plays important roles in the provision of ecosystem services such as a medium for plant growth, supplying important resources of water and nutrients, cycling of nutrients of carbon and nitrogen regulation of gas inflows from the subsurface and the atmosphere (Jimenez *et al.,* 2022). The ability of soil to perform these functions is dependent on the type of parent material the soil originated from. Not only this, the ability of soil to supply important nutrients and elements to plants as well as the production of quality crop produce or vice versa in a given community is all tied to the parent material a soil originated from. More so, the proneness of soil to degradation and the frequency of weathering are also tied to parent soil materials (Afu *et al.,* 2021).

Reports show that the soils found in humid tropics are much more fertile than soils found in non-humid tropics and thus better for agricultural activities. This is in clear contrast to the beliefs of many people lacking the knowledge of soil pedogenetic processes as they consider soils of all types to have the same ability of crop production, particularly, when the soils are found in the same geographical location (Afu *et al.,* 2017). Afu *et al.* (2017) reported that soils formed through different parent materials are different in their physicochemical properties. In another report, soils within the same agro-ecological conditions vary significantly in their differences in parent materials (Irmak *et al*., 2016). Different soils are made from different parent materials and this factor influences crop yields of different agricultural produce. Ofem *et al.* (2020) reported that soils in Ogoja community developed solely on limestone, shale, sandstones and basement complex formation. Interestingly, this area has been reported to produce higher crop yields compared to other areas of different parent materials.

CONCLUSION

In this review, different processes of soil formation through weathering are drivers of biogeochemical cycling of mineral nutrient elements. Plants use these elements for various biochemical processes. Sedimentary rocks are used to produce different soil parent materials. These materials dictate and control how plants are supplied with nutrient mineral elements that enhance the production of quality agricultural crop produce in a given community.

CONFLICT OF INTEREST

The authors declare the they have no conflict of interest.

ACKNOWLEDGMENTS

The authors are thankful to the Federal University Gusau and are immensely grateful to the Tertiary Education Trust Fund (TETFUND) for their financial support.

REFERENCES

Abdullahi, A., Lawal, M. A., & Salisu, A. M. (2021). Heavy Metals in Contaminated Soil: Source, Accumulation, Health Risk and Remediation Process. *Bayero Journal of Pure and Applied Sciences, 14*(1), 1-12.

Afu, S. M., Isong, I. A., & Aki, E. E. (2017). Variability of selected physico-chemical properties of soil overlying different parent materials in Odukpani, Cross River State. *International Journal of Plant and Soil Science, 20*(6), 1-14.

Afu, S. M., Isong, I. A., Akpan, J. F., Olim. D. M., & Eziedo, P. C. (2021). Spatial assessment of heavy metal contamination in agricultural soils developed on basaltic and sandstone parent materials. *Journal of Environmental Science and Technology*, *14*, 21-34.

Brantley, S. L., Buss, H., Lebedeva, M., Fletcher, R. C., Ma, L. (2011). Investigating the complex interface where bedrock transforms to regolith. *Applied Geochemistry*, *26*, S12-S15.

Buss, H. L., Lara, M. C., Moore, O. W., Kurtz, A. C., Schulz, M. S., & White, A. F. (2017). Lithological influences on contemporary and long-term regolith weathering at the Luquillo Critical Zone Observatory. *Geochimica et Cosmochimica Acta*, *196*, 224-251.

Chapela Lara. C., Buss, H. L., & Pett-Ridge, J. C. (2018). The effects of lithology on trace element and REE behavior during tropical weathering. *Chemical Geology*, *500*, 88-102.

Cox, P. A. (1995). The elements on earth, inorganic chemistry in the environment. Oxford University Press Inc., New York.

Dawson, R. L., Calear, A. L., McCallum, S. M., McKenna, S., Nixon, R. D., & O'Kearney, R. (2020). Exposure-based writing therapies for subthreshold and clinical posttraumatic stress disorder: A systematic review and meta-analysis. *Journal of Traumatic Stress*, *34*(1), 81-91.

Fang, W., Hu, R., & Wu, P. (2002). Influence of black shales on soils and edible plants in the Ankang area, Shaanxi Province, PR of China. *Environmental Geochemistry and Health*, *24*, 35-46.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., & Snyder, P. K. (2005). Global consequences of land use. *Science*, *309*(5734), 570-574.

Frings, P. J., & Buss, H. L. (2019). The central role of weathering in the geosciences. *Elements: An International Magazine of Mineralogy, Geochemistry, and Petrology*, *15*(4), 229-234.

Garí, J. A. (2003). Agrobiodiversity strategies to combat food insecurity and HIV/AIDS impact in rural Africa. Advancing Grassroots Responses for Nutrition, Health and Sustainable Livelihoods, Population and Development Service, FAO, Rome, Italy, 2003

Hu, X., Wei, X., Ling, J., & Chen, J. (2021). Cobalt: an essential micronutrient for plant growth? *Frontiers in Plant Science*, *12*, 768523.

Irmak, S., Surucu, A. K., & Aydogdu, I. H. (2007). Effects of different parent material on the mineral characteristics of soils in the arid region of Turkey. *Pakistan Journal of Biological Sciences*, *10*(4), 528-536.

Jimenez, L. C. Z., Queiroz, H. M., Cherubin, M. R., & Ferreira, T. O. (2022). Applying the soil management assessment framework (SMAF) to assess mangrove soil quality. *Sustainability*, *14*(5), 3085.

Kabata-Pendias, A. and Pendias, H. (2002). Trace elements in soils and plants. Lewis, Boca Raton.

Kwong, Y. J., Whitley, G., & Roach, P. (2009). Natural acid rock drainage associated with black shale in the Yukon Territory, Canada. *Applied Geochemistry*, *24*(2), 221-231.

Lee, S., & Aronoff, S. (1967). Boron in plants: a biochemical role. *Science*, *158*(3802), 798-799.

Lewis, D. H. (2019). Boron: The essential element for vascular plants that never was. *New Phytologist*, *221*(4), 1685-1690.

Malhotra, N., Hsu, H. S., Liang, S. T., Roldan, M. J. M., Lee, J. S., Ger, T. R., & Hsiao, C. D. (2020). An updated review of toxicity effect of the rare earth elements (REEs) on aquatic organisms. *Animals*, *10*(9), 1663.

Moore, G. F., Evans, R. E., Hawkins, J., Littlecott, H. J., & Turley, R. (2017). All interventions are complex, but some are more complex than others: using iCAT_SR to assess complexity. *The Cochrane Database of Systematic Reviews*, *7*, ED000122.

Moore, L., Hallingberg, B., Wight, D., Turley, R., Segrott, J., Craig, P., Robling, M., Murphy, S., Simpson, S. A., & Moore, G. (2018). Exploratory studies to inform full-scale evaluations of complex public health interventions: the need for guidance. *Journal of Epidemiol Community Health*, *72*(10), 865-866.

Nganje, T. N., & Adamu, C. I. (2014). A Comparative Study of Element Cycling in the Soil-Plant System: A Case Study of Shaly and Calcareous Soils, Southern Benue Trough, Nigeria. *International Journal of Geosciences*, *5,* 453-463.

Ofem, K. I., Asadu, C. L. A., Ezeaku, P. I., Kingsley, J., Eyong, M. O., Katerina, V., Václav, T., Karel, N., Ondřej, D., & Vít, P. (2020). Genesis and classification of soils over limestone formations in a tropical humid region. *Asian Journal of Scientific Research*, *13*, 228-243.

Ogunbode, A. A., Mustapha, T. B., Adams, T. O., Stephen, F. T., & Amusat, W. A. (2021). Evaluation of selected minerals in the blood of crossbred pigs fed toasted soybean hull. *Nigerian Journal of Animal Production*, *48*(1), 135-141.

Ozcan, M. (2003). Mineral contents of some plants used as condiments in Turkey. *Food Chemistry*, *84*, 437-440.

Porder, S., Johnson, A. H., Xing, H. X., Brocard, G., Goldsmith, S., & Pett-Ridge, J. (2015). Linking geomorphology, weathering and cation availability in the Luquillo Mountains of Puerto Rico. *Geoderma*, *249*, 100-110.

Siegel, F. R. (2002). *Environmental geochemistry of potentially toxic metals* (Vol. 32). Berlin: springer.

Soetan, K. O., Olaiya C. O., & Oyewole, O. E. (2010). The importance of mineral elements for humans, domestic animals and plants - A review. African Journal of Food Science, *4*(5), 200- 222.

Uhlig, D., & von Blanckenburg, F. (2019). Geochemical and isotope data on rock weathering, and nutrient balances during fast forest floor turnover in montane, temperate forest ecosystems. *GFZ Data Services. Retrieved from http://doi.org/10.5880/GFZ.3.3.2019.004*

Uhlig, D., Schuessler, J. A., Bouchez, J., Dixon, J. L., & von Blanckenburg, F. (2017). Quantifying nutrient uptake as driver of rock weathering in forest ecosystems by magnesium stable isotopes. *Biogeosciences*, *14*(12), 3111-3128.

Williams, U. S. (2020). *A revised textbook of Biology*. Cheltenham, Nelson Thornes.

Yeboah, J. O., Shi, G., & Shi, W. (2021). Effect of heavy metal contamination on soil enzymes activities. *Journal of Geoscience and Environment Protection*, *9*(6), 135-154.