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Forest Soil Quality and Potentials for Food Systems Health in the Takamanda National Park in South Western Cameroon

Mary E. Ngaiwi, Ernest Molua, A. E. Egbe

Faculty of Agriculture and Veterinary Medicine, University of Buea, Cameroon
Email: cidr@cidrcam.org, maryngaiwi@gmail.com

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Abstract

Soil is a basic natural resource for food production, the vast majority of food we consume is either directly or indirectly derived from soil. Soil quality determines the quantity and quality of foods grown. Protecting the soil's physical, chemical and biological integrity is therefore of vital importance in safeguarding global food security. This paper evaluates the physical and chemical properties of soils in the rainforest of the Takamanda in Southwestern Cameroon and their implications on agricultural productivity and food security. Soils were randomly sampled using a bucket soil auger at the left, middle and right flank of the 50 ha Takamanda forest dynamic plot. Soils were sampled from three flanks at depths of 0 - 10 cm, 10 - 20 cm and 20 - 30 cm. Bulk density increased with soil depth in all the flanks. Soil nitrogen, organic carbon, potassium, magnesium, sodium, phosphorus and cation exchange capacity were greater in topsoil (0 - 10 cm) than subsoils. Soil Ca and pH were slightly greater at 20 - 30 cm soil depths with value of 0.45 cmol (+)/kg and 4.24 respectively. Soil C/N ratio was highest (13.12) in 10 - 20 cm soil depth though it was not significantly different from the other soil depths. To promote food production, an integrated cost-effective approach to soil management should comprise the use of acid-tolerant species of crop plants, efficient use of fertilizers, suitable crop rotations, crop diversification and agroforestry.

Keywords

Rainforest Soil, Productivity, Macronutrients, Food Security, Cameroon

1. Introduction

Agriculture and food systems have changed very much over the last 50 years. Agricultural development has seen a rapid advance of agricultural technology in industrialized countries with the green revolution in the 1960s being counteracted by an increasing public awareness of environmental protection and sustainable development that evolved in the 1980s [1]. Achieving food and nutritional security requires every member of society to have access to nutritious food and the information and freedom to make appropriate choices concerning good nutrition. In this light, people who are fed properly are healthier, but nutritional and health linkages differ widely. For example, the stunting and wasting of under-five children which is widespread in rural areas of South Asia and Sub Saharan Africa is an entirely different problem than the increasing obesity or concerns about food quality and safety in rapidly urbanizing populations. It is broadly accepted that an adequate and balanced diet provided through effective agricultural production results in healthier children and communities [2]. Food availability relies on soils: nutritious and good quality food and animal fodder can only be produced if our soils are healthy. Healthy soil is therefore a crucial ally to food security and nutrition [3] [4] [5]. The most widely recognized function of soil is its support for food production. It is the foundation for agriculture and the medium in which nearly all food-producing plants grow. In fact, it is estimated that 95% of our food is directly or indirectly produced on our soils [6]. Healthy soils supply the essential nutrients, water, oxygen and root support that our food-producing plants need to grow and flourish. Soils also serve as a buffer to protect delicate plant roots from drastic fluctuations in temperature [7] [8]. Soil health has been defined as the capacity of soil to function as a living system. Healthy soils maintain a diverse community of soil organisms that help to control plant disease, insect and weed pests, form beneficial symbiotic associations with plant roots, recycle essential plant nutrients, improve soil structure with positive effects for soil water and nutrient holding capacity, and ultimately improve crop production. Healthy soil also contributes to mitigating climate change by maintaining or increasing its carbon content [6].

Soil's dynamic natural body comprising of unconsolidated mineral and organic matter including water and air on the uppermost layers of earth surface plays an important role in maintaining the ecosystem functioning on which all life depends [9]. Foresters have always relied on knowledge of chemical and physical properties of soils to assess the capacity of sites to support productive forests. Recently, the need for assessing soil properties has expanded because of growing public interest in determining the consequences of management practices on the quality of soil, relative to the sustainability of forest ecosystem functions in addition to plant productivity. The concept of soil quality includes assessment of soil properties and processes as they relate to the ability of soil to function effectively as a component of a healthy ecosystem [10].

In natural forests, nutrients are efficiently cycled with very small inputs and outputs from the system. Tropical forest soils are comprised of the original geologic mineral substrate that has been deposited across the topography of the landscape, acted upon by various biotic organisms, and over time weathered by the climate conditions of the region. The most biologically active portion of any soil is near the surface, where the levels of oxygen and water are most conducive for plant root growth and microorganism activity. Soil is perhaps the most remarkable habitat on Earth that is harboring rich biodiversity. Soil biota is responsible for the turnover of organic matter and the transformation of nutrients, such as nitrogen and sulphur, thus is an integral part of soil quality [11]. The pre-eminence of soil as the basic natural resource for food production makes soil science an indispensable discipline in safeguarding global food security [12]. Due to the long association between soil science and agriculture, the term "soil health" has traditionally been associated solely with the capacity of the soil to promote plant growth. Renewed interest in principles of sustainable management has expanded this definition to recognize the broader role that soils play in regulating key ecosystem functions such as protecting watersheds through regulation of infiltration and runoff, preventing and mitigating pollution inputs, and providing physical support as a foundation material for roads and other development [13].

The widely acknowledged and growing threat of food insecurity [14]-[19], rapidly engulfing poor and under-privileged population across the globe [17] [18] [19], necessitates a critical appraisal of agronomic strategies needed to enhance and sustain productivity while mitigating climate change, improving biodiversity, restoring quality of soil and water resources, and improving the environment [13] [20] [21] [22]. In most agricultural systems the opposite happens. Agroforestry encompasses the continuum between these extremes, and emerging hard data is showing that successful agroforestry systems increase nutrient inputs, enhance internal flows, decrease nutrient losses and provide environmental benefits—when the competition for growth resources between the tree and the crop component is well managed. The continuing threat to the world's land resources is exacerbated by protracted rural poverty and food insecurity in the Third World, and wider climatic variations resulting from global warming [23]. During the last decade, food security was not a global priority, but studies such as the 2020 Vision show that rural poverty in the third world is one of the main global concerns of our time, and that food insecurity is a major factor in rural poverty. Access to sufficient and nutritious food for all is the key to poverty alleviation—this was one of the main outcomes of the 1996 World Food Summit [24]. Food security encompasses both food production and the ability to purchase food. However, calories and protein are not the only factors: nutritional security includes overcoming deficiencies of vitamin A, iron, zinc, iodine, and selenium (IFPRI, 1996). It is also recognized that the attainment of food security is intrinsically linked with safeguarding the natural resource (e.g. soils) base [25]. Therefore, the three interlinked factors for reversing rural poverty are 1) income generation, 2) increasing food and nutritional security, and 3) protecting the environment. Soil is considered a non-renewable resource as it takes thousands of years to form from eroding rocks and sediments and requires very specific topographical, meteorological, and biological conditions. This underappreciated phenomenon has resulted in the unsustainable pillaging of the Earth's soil through intense agricultural practices and has resulted in reduced soil health. Soil health and food security go hand in hand and with estimates of the human population reaching 9 billion by 2050, a greater understanding and appreciation of soil needs to be reached. Only now are we starting to observe the effects of poor soil health on food production and appreciate the importance of maintaining healthy soils for greater food security. Healthy soils function as living systems; they boast a huge diversity of micro-organisms (microbes) and provide vital services. These microbes maintain soil structure (soil is highly structured contrary to popular belief), regulate nutrient and water cycles within the soil and the atmosphere (including soil detoxification and decomposition of organic matter), carbon sequestration (*i.e.* the capture and long-term storage of atmospheric carbon dioxide, which aids in the mitigation of climate change), and are involved in symbiotic relationships with plants (some bacteria and fungi capture atmospheric nitrogen and convert it into a usable form for plants) [6].

The United Nations in its Sustainable Development Goals (SDGs) aims by 2030 to "end hunger, achieve food security and improve nutrition and promote sustainable agriculture". This calls for technology-solutions and agriculture-based innovations. While increasing forest conservation may limit land access for agriculture, for instance, it is expected that its conservation will rejuvenate soil biophysical health, with natural mineralisation playing a pivotal role in achieving crop production growth through higher yields and increased cropping intensity. However, there is increasing soil acidification [26] [27] [28], and it has become an important problem in staple food production [3] [5] [29]. Ameliorating or remedying the acidification of tropical soils has important theoretical and practical significance for rebuilding healthy soils and guaranteeing national food security. As observed in [30] fertile soil is fundamental to our ability to achieve food security, but problems with soil degradation, such as acidification, are exacerbated by poor management. This paper therefore evaluates the physical and chemical properties of forest soils in the rainforest of the Takamada and their implications to agricultural productivity and food security. The remainder of the paper is structured as follows. Section 2 presents the materials and methods, the results are presented in Section 3 following by discussion and conclusion in Sections 4 and 5, respectively.

2. Materials and Methods

2.1. Site Description

The study was carried out in the rainforest of Takamanda National Park, Manyu Division in the South West Region of Cameroon. Precisely between geographical coordinates: 05˚59' - 06˚21'N and 09˚11 - 09˚30'E. The rainforest is situated at the northern corner of the South West Region of Cameroon and partly in the Northeast of the extensive Cross River Valley along the Eastern border of Nigeria. The region has two distinct seasons with most rainfall occurring from July to October with the peaks in September and August. From November to February, the climate is mainly dry. Some months usually December, January, February may receive little or no rain at all. The monthly maximum temperature is about 33.4˚C and minimum temperatures of 26.4˚C with mean annual temperature of 26.48˚C. This Park is a hotspot for biodiversity conservation. Gorillas from this region are geographically and morphologically distinct from other gorillas [31], and they are now recognized as the fourth gorilla subspecies the Cross River gorilla and classified as critically endangered [32]. The forests of Takamanda are also important for a great diversity of birds as recognized by Birdlife International when it designated the Reserve an important Bird Area. Reptile diversity is equally impressive, Butterflies (111 species) [33] [34], and dragonflies (67 species) have high levels of diversity. Both groups are important indicators of forest change. Likewise, 54 species of fish were registered, many of which provide an important protein source to local communities [ibid]. Flora also proves to be extremely rich with more than 950 species of plants registered over the course of the present surveys. Of these, 351 species were trees with diameters greater than 10 cm [ibid]. In Manyu, agriculture is also the most dominant economic activity, with both indigenous and settlers involved in subsistence food crop farming of cocoyam, yellow coco (Akwana), taro (Ibo-coco), plantains, cassava, yams, maize, tropical fruits and vegetables. Cash crop farming includes cocoa, coffee, palm nuts and rubber. Plantain agriculture is also carried out in here [35]. But specifically around the Takamanda area only Cassava and Plantain are the main crops cultivated.

2.2. Collection and Preparation of Soil Samples

Soils were randomly sampled using a bucket soil auger at the left, middle and right flank of the 50 ha Takamanda forest dynamic plot. Soils were carefully collected at the following depths 0 - 10 cm, 10 - 20 cm and 20 - 30 cm as the auger was marked with bold marker with respect to the various depths. The soils were put in plastic bags and labelled for each soil depth and these were taken to the laboratory for air-drying. They were later sieved using a 2 mm sieve, labelled and analysed for particle size and for soil chemical properties. Bulk density was determined using soil cores. The mass and volume of the cores were assessed. The mass of the soil plus core was taken using a sensitive balance and this was later oven-dried at 105˚C for 72 hours. After oven drying, the soil plus core was weighed and the weight recorded. The mass of the oven-dried soil, was obtained by subtracting the mass of core from the mass of oven-dry soil plus core. The volume of the core was determined by taking the internal diameter of the core and the height of the core was measured with a tape. The volume of the core was calculated using the formula $\pi r^2 h$.

2.3. Chemical Analysis of Soil Samples

The sieved soils were analysed for the following soil properties; Soil pH in water was determined in a 1:2.5 (w/v) soil: water suspension. Organic carbon was determined by chromic acid digestion and spectrophotometric analysis [36]. Total nitrogen was determined from a wet acid digest [37], and analyzed by colorimetric analysis [38]. Exchangeable calcium, magnesium, potassium, and sodium were extracted using the Mehlich-3 procedure [39], and determined by atomic absorption spectrophotometry. Available Phosphorus was extracted by Bray-1 procedure and analyzed using the molybdate blue procedure described by temperature [7] [8] [40]. Cation exchange capacity was determined by ammonium acetate method at pH 7. Phosphorus was expressed in parts per million (ppm) or ug/g; CEC, Ca, Mg, K, and Na reported as cmol (+)/kg or meq/100g of soil. Organic carbon and total nitrogen were expressed as percentages. Particle size (clay, silt and sand) was determined by the hydrometer method [41].

3. Results and Discussion

3.1. Soil Physical Properties

Bulk density increased with soil depth in all the flanks in the 50 ha Takamanda forest dynamic plot and ranged from 1.24 to 1.75 g/cm^3 (**Table 1**). The least bulk density was observed in the left flank 0 - 10 cm soil depth while the highest bulk density was recorded in the 20 - 30 cm soil depth at the right flank. Percentage soil moisture was observed to be high in the top 0 - 10 cm soil depths for all the three flanks. The soil texture from particle size analysis showed that the soils were sandy clay loam soils. Bulk density is dependent on soil organic matter, soil texture, the Density of soil mineral (sand, silt, and clay) and their packing arrangement. As a rule of thumb, most rocks have a density of 2.65 g/cm so ideally, a silt loam soil has 50% pore space and a bulk density of 1.33 g/cm. Generally, loose, well aggregated, porous soils and those rich in organic matter have lower bulk density. Sandy soils have relatively high bulk density since total pore space in sands is less than silt or clay soils. Bulk density typically increases with soil depth since subsurface layers are more compacted and have less organic matter, less aggregation, and less root penetration compared to surface layers, therefore contain less pore space.

Table 1. Some soil physical properties of Takamanda forest dynamic plot.

				% particle size		
SITES	Depth/cm	bulk density	%Moisture content	Sand	Clay	Silt
Left flank	0 - 10	1.24 ± 0.15	8.4 ± 1.48	64.17 ± 2.07	27.78 ± 1.31	11.06 ± 0.83
	10 - 20 cm	1.68 ± 0.12	3.7 ± 0.74	60.1 ± 1.59	28.12 ± 1.68	11.78 ± 0.23
	20 - 30 cm	1.71 ± 0.11	4.3 ± 1.68	57.04 ± 0.30	29.12 ± 0.66	13.84 ± 0.37
Middle flank	0 - 10 cm	1.24 ± 0.15	5.3 ± 1.48	57.51 ± 2.07	30.12 ± 1.31	12.37 ± 0.83
	10 - 20 cm	1.56 ± 0.12	2.8 ± 0.74	58.17 ± 1.59	30.19 ± 1.68	11.64 ± 0.23
	20 - 30 cm	1.64 ± 0.11	3.6 ± 1.68	53.1 ± 0.30	35.19 ± 0.66	11.71 ± 0.37
Right flank	0 - 10 cm	1.35 ± 0.15	8.7 ± 1.48	53.17 ± 2.07	34.19 ± 1.31	12.64 ± 0.83
	10 - 20 cm	1.64 ± 0.12	6.1 ± 0.74	52.46 ± 1.59	36.12 ± 1.68	11.42 ± 0.23
	20 - 30 cm	1.75 ± 0.11	2.9 ± 1.68	52.17 ± 0.30	36.19 ± 0.66	11.64 ± 0.37

Note: Texture class for all the flanks is the Sandy clay loam.

The soils here were sandy clay loam and the bulk density increased with depth, thus these soils are just perfect for agricultural activities leading to an increase in agricultural productivity. This is so because these soils are tropical rainforest soils that are not disturbed. Tillage destroys soil organic matter and weakens the natural stability of soil aggregates making them susceptible to erosion caused by water and wind. When eroded soil particles fill pore space, porosity is reduced and bulk density increases thus leading to a decrease in agricultural productivity. These results thus affirm the importance of No-Till technique as an important climate-smart agricultural practice to enhance soil Productivity.

3.2. Soil Chemical Properties

Soil nitrogen, organic carbon, potassium, magnesium, sodium, phosphorus and cation exchange capacity were greater in topsoil (0 - 10 cm) than subsoils (**Table 2**). Soil Ca and pH were slightly greater at 20 - 30 cm soil depths with value of 0.45 cmol (+)/kg and 4.24 respectively. Soil C/N ratio was highest (13.12) in 10 - 20 cm soil depth though it was not significantly different from the other soil depths (**Table 2**). Nitrogen is a key element in plant growth. It is found in all plant cells, in plant proteins and hormones, and in chlorophyll. Nitrate is easily leached out of soil by heavy rain, resulting in soil acidification. Thus the presence of high levels of nitrogen in these soils is an indication of their fertility and thus agricultural productive soils. Phosphorus helps transfer energy from sunlight to plants, stimulates early root and plant growth, and hastens maturity. Potassium increases vigour and disease resistance of plants, helps form and move starches, sugars and oils in plants, and can improve fruit quality. Muriate of potash and sulfate of potash are the most common sources of potassium. Calcium is essential for root health, growth of new roots and root hairs, and the development of leaves. Magnesium is a key component of chlorophyll, the green colouring material of plants, and is vital for photosynthesis (the conversion of the sun's energy to food for the plant). The presence of these nutrients in high levels in these soils, coupled with the favourable bulk density is an indication that these soils are fertile and should be maintained and managed for sustainability likewise other soils of different areas.

Table 2. Some soil chemical properties.

Depth/cm	pH	%C	%N	P(ug/g)	Cmol(+)/kg					C/N
					K	Ca	Mg	Na	CEC	
0 - 10	3.92	1.67	0.14	2.62*	0.22*	0.24	0.35	0.02	6.89	11.93
10 - 20	3.92	1.46	0.11	2.33	0.10	0.15	0.34	0.01	4.99	13.27
20 - 30	4.24*	1.35	0.12	0.88	0.11	0.45	0.29	0.01	6.08	11.25
Mean	4.03	1.49	0.12	1.94	0.14	0.28	0.33	0.01	5.98	12.15
LSD	0.18	0.58	0.05	1.59	0.06	0.20	0.35	0.01	0.94	1.19
P Values	0.01	0.44	0.35	0.01	<0.001	0.03	0.92	0.08	0.01	0.05

4. Discussion

Soil pH in the study site increased with depth. This was comparable to the findings in [42] in tropical rainforests of Brazil with the pH of the study site with a range of 3.93 to 4.24. This was in the acidic range which disagreed with the findings in [43], which reported that pH of the soils of Ondo state rainforest of Nigeria is slightly acidic to neutral. This might be due to high concentration of high valence ions like Al, Fe, Mn, or silicic acid which will tend to displace those with lower valences such as H^+; thus when this H^+ is displaced into the soil. This can have toxic effects on plants and soil organisms but under dense vegetation such as tropical rainforests, this effect is generally not as marked because of the rapid uptake of basic nutrients (K^+, Ca^{2+}, Mg^{2+}) by the plant root system, causing an increase in pH levels [44].

Cation exchange capacity of the soil was low in this study site and total nitrogen, phosphorus and potassium decreased with depth. This trend in total nitrogen may be due to the level of organic matter in topsoils and its decomposition. References [8] and [42] also made similar observations in Brazilian tropical forest. Cation exchange of tropical soil is generally low due to the predominance of low activity clays and lack of 2:1 phyllosilicates; also it may be because of the low concentrations of organic matter [45].

Organic carbon decreased with depth, implying that there were high organic carbon concentrations on topsoils. This might have occurred because of high organic matter deposition on top soils thus more organic carbon due to decomposition, which is similar to the findings by [43].

Bulk density of the study site increased with soil depth. This agreed with the findings in [44]. Bulk density is dependent on soil texture and the densities of soil mineral (silt, sand and clay) and organic matter particles as well as their parking arrangement. It increases with depth since subsurface layers have reduced organic matter, aggregation and root penetration. Thus, bulk density reflects the soil's ability to function for structural support, water and solute movement and soil aeration. The highest topsoil bulk density for all the three flanks was 1.35. That of subsoils was 1.75. High bulk density is an indicator of low porosity and compaction, which may cause restrictions to root growth and poor movement of air and water through the soil.

This finding of the soil being associated with acidification and toxicities as well as deficiencies and other plant restricting conditions, is instructive for the state of food production in the study site, an important objective for sustainable forest management and healthy community relations. As noted in [46], the management of optimal soil pH is fundamental to sustainable crop production. Unobtrusive observation of dominant food crops reveals interesting physiognomies that strain both the vegetative and reproductive growth. For example, deformed and brittle root tips, reduced root growth and branching. This further translates into poor crop and pasture growth, crop yield reduction and smaller tuber and grain size occur as a result of inadequate nutrition. This is expected as roots are unable to effectively grow through acidic subsurface soil, which forms a barrier and restricts access to stored subsoil water. Sustainable land management will require periodic soil testing by the agricultural extension service to determine the lime requirements to neutralize soil acidity to the desired level [47]. In addition, the negative effects of soil acidity on physical and chemical soil conditions can be partly compensated by ensuring high organic matter content [29] [48]. This would imply lime could be applied as a preventative treatment for soil infertility [49] [50], and to correct for calcium and magnesium deficiency. As reference [26] notes, liming would improve soil structure and raise the pH, thus the action of nitrogen-fixing bacteria becomes uninhibited and nitrogen fixation increases. Nitrogen mineralization from plant residues and organic matter has been reported to increase when lime is applied to acid soil [5] [29] [48].

5. Conclusion

The soils of this area under study are acidic thus impacting negatively on the nutrients' availability to plants. Agricultural systems not only sustain life through food security, but also ensure rural livelihood through market opportunities and incomes. An important pillar of food security is food availability through sustained production levels. The acidification of the soils under study causes the loss of base cations, lead to a possible increase in aluminum saturation and a corresponding decline in crop yields. Measures are required, since severe acidification can cause non-reversible clay mineral dissolution and a reduction in cation exchange capacity, accompanied by structural deterioration of the soils, on which the surrounding communities depend. Rainforest soils like that of the Takamanda are typically fertile and key to the large diversity for these forests, however, in strengthening food security, an integrated cost-effective approach to soil management should comprise the use of acid-tolerant species of crop plants, efficient use of fertilizers, suitable crop rotations and crop diversification. More importantly, some tree species in these forests should be introduced to agricultural systems in forms of agroforestry to improve on soils in the Takamanda for further enhancement of their productivity.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] FAO (2005) The Food and Agriculture Organization Corporate Statistical Database. FAO, Rome, Italy.

[2] Masset, E. (2011) A Review of Hunger Indices and Methods to Monitor Country Commitment to Fighting Hunger. *Food Policy*, **36**, S102-S108 https://doi.org/10.1016/j.foodpol.2010.11.007

[3] Ciceri, D. and Allanore, A. (2019) Local Fertilizers to Achieve Food Self-Sufficiency in Africa. *Science of the Total Environment*, **648**, 669-680.

https://doi.org/10.1016/j.scitotenv.2018.08.154

[4] Zhu, Y.-G. (2009) Soil Science in the Understanding of the Security of Food Systems for Health. *Asia Pacific Journal of Clinical Nutrition*, **18**, 516-519.

[5] Connor, D.J., Loomis, R.J. and Cassman, K.G. (2011) Crop Ecology: Productivity and Management in Agricultural Systems. 2nd Edition, Cambridge University Press, Cambridge.

[6] FAO (2015) The State of Food and Agriculture. FAO, Rome, Italy.

[7] Hinsinger, P., Plassard, C., Tang, C. and Jaillard, B. (2003) Origins of Root-Mediated pH Changes in the Rhizosphere and Their Responses to Environmental Constraints: A Review. *Plant and Soil*, **248**, 43-59. https://doi.org/10.1023/A:1022371130939

[8] Patricia, L. and Morellato, C. (1992) Nutrient Cycling in Two South-East Brazilian Forests. I Litterfall and Litter Standing Crop. *Journal of Tropical Ecology*, **8**, 205-215. https://doi.org/10.1017/S0266467400006362

[9] Agyemang, O., Golow, A.A. and Serfor-Armah, Y. (2011) Soil Fertility Analysis in Two Orange Farm Towns in Assin North District of the Central Region of Ghana. *Elixir*, **37**, 3629-3632.

[10] Schoenholtz, S.H., Van Miegroet, H. and Burger, J.A. (2000) A Review of Chemical and Physical Properties as Indicators of Forest Soil Quality: Challenges and Opportunities. *Forest Ecology and Management*, **138**, 335-356. https://doi.org/10.1016/S0378-1127(00)00423-0

[11] Wardle, D.A., Bardgett, R.D., Klironomos, J.N., Setala, H., van der Putten, W.H. and Wall, D.H. (2004) Ecological Linkages Between Aboveground and Belowground Biota. *Science*, **304**, 1629-1633. https://doi.org/10.1126/science.1094875

[12] Molua, E.L., delos Angeles, M.S. and Mbwangue, J. (2015) Sustaining Soil Natural Capital Through Climate-Smart Farmland Management. *Nature & Faune*, **30**, 81-84.

[13] Lal, R. (2006) Managing Soils for Feeding a Global Population of 10 Billion. *Journal of the Science of Food and Agriculture*, **86**, 2273–2284. https://doi.org/10.1002/jsfa.2626

[14] Brown, L.R. (2008) Why Ethanol Production Will Drive World Food Price Even Higher in 2008? Earth Policy Institute, Columbia.

[15] Anon (2008) The New Face of Hunger. *The Economist*, 17 April 2008.

[16] FAO (2006) The State of Food Insecurity in the World. FAO, Rome, Italy.

[17] FAO (2007) Food Balance Sheet 1961-2006. FAO, Rome, Italy.

[18] FAO (2007) Food Outlook 2007: Global Market Analysis. FAO, Rome, Italy.

[19] FAO (2007) The State of Food and Agriculture: Paying Farmers for Environmental Services. FAO, Rome, Italy.

[20] Lal, R. (2004) Soil Carbon Sequestration Impacts on Global Climate Change and Food Security. *Science*, **304**, 1623-1627. https://doi.org/10.1126/science.1097396

[21] Lal, R. (2006) Enhancing Crop Yields in the Developing Countries Through Restoration of the Soil Organic Carbon Pool in Agricultural Lands. *Land Degradation & Development*, **17**, 197-209. https://doi.org/10.1002/ldr.696

[22] Sanchez, P.A. (2002) Soil Fertility and Hunger in Africa. *Science*, **295**, 2019-2020. https://doi.org/10.1126/science.1065256

[23] Anon (2008) The Silent Tsunami. *The Economist*, 17 April 2008.

[24] FAO(1996) The State of Food Insecurity in the World. FAO, Rome, Italy.

[25] International Food Policy Research Institute (IFPRI) (1996) IFPRI Annual Report, Washington DC.

[26] Goulding, K.W.T. (2016) Soil Acidification and the Importance of Liming Agricultural Soils with Particular Reference to the United Kingdom. *Soil Use* and *Management*, **32**, 390-399. https://doi.org/10.1111/sum.12270

[27] Ngaiwi, E.M., Molua, E.L. and Egbe, A.E. (2018) Litterfall and Nutrient Returns in the Rainforest of Southwestern Cameroon: Some Implications for Tropical Forest Productivity. *Environment and Natural Resources Research*, **8**, 25-32, https://doi.org/10.5539/enrr.v8n3p25

[28] Rengel, Z. (2003) Handbook of Soil Acidity. Marcel Dekker, New York. https://doi.org/10.1201/9780203912317

[29] Haynes, R.J. and Naidu, R. (1998) Influence of Lime, Fertilizer and Manure Applications on Soil Organic Matter Content and Soil Physical Conditions: A Review. *Nutrient Cycling in Agroecosystems*, **51**, 123-137. https://doi.org/10.1023/A:1009738307837

[30] Holland, J.E., Bennett, A.E., Newton, A.C., White, P.J., McKenzie, B.M., George, T.S., Pakeman, R.J., Bailey, J.S., Fornara, D.A. and Hayes, R.C. (2018) Liming Impacts on Soils, Crops and Biodiversity in the UK: A review. *Science of the Total Environment*, **610-611**, 316-332. https://doi.org/10.1016/j.scitotenv.2017.08.020

[31] Sarmiento, E.E. and Oates, J.F. (2000) The Cross River Gorillas: A Distinctive Subspecies, *Gorilla gorilla diehli* Matschie 1904. *American Museum Novitates*, **2000**, 1-55. https://doi.org/10.1206/0003-0082(2000)3304<0001:TCRGAD>2.0.CO;2

[32] Anon (2008) Deserting the Hungry. *Nature,* **451**, 223-224. https://doi.org/10.1038/451223b

[33] Sunderland-Groves, J.L., Sunderland, T.C.H., Comiskey, J.A., Ayeni, J.S.O. and Mdaihli, M. (2003) Takamanda Forest Reserve, Cameroon. In: Comiskey, J.A. and Sunderland, T.C.H., Eds., *Takamanda*: *The Biodiversity of an African Rainforest*. SI/MAB Series #8, Washington DC, 1-8.

[34] Ndumbe, L., Ingram, V. and Awono, A. (2009) Eru Market Chain Baseline (Gnetum spp.) in the Southwest and Littoral Regions, Cameroon. GCP/RAF/408/EC.

[35] Heanes, D.L. (1984) Determination of Total Organic-C in Soils by an Improved Chromic Acid Digestion and Spectrophotometric Procedure. *Journal Communications in Soil Science and Plant Analysis*, **15**, 1191-1213. https://doi.org/10.1080/00103628409367551

[36] Buondonno, A., Rashad, A.A. and Coppola, E. (1995) Comparing Tests for Soil Fertility. II. The Hydrogen Peroxide/Sulfuric Acid Treatment as an Alternative to the Copper/Selenium Catalyzed Digestion Process for Routine Determination of Soil Nitrogen-Kjeldahl. *Communications in Soil Science and Plant Analysis*, **26**, 1607-1619. https://doi.org/10.1080/00103629509369394

[37] Anderson, J.M. and Ingram, J.S.I. (1993) Tropical Soil Biology and Fertility: A Handbook of Methods. 2nd Edition, CAB International, The Cambrian News, Aberstwyth, UK, 221.

[38] Mehlich, A. (1984) Mehlich 3 Soil Test Extractant: A Modifcation of Mehlich 2 Extractant. *Communications in Soil Science and Plant Analysis*, **15**, 1409-1416. https://doi.org/10.1080/00103628409367568

[39] Haynes, R.J. and Naidu, R. (1998) Influence of Lime, Fertilizer and Manure Applications on Soil Organic Matter Content and Soil Physical Conditions: A Review. *Nutrient Cycling in Agroecosystems*, **51**, 123-137.

https://doi.org/10.1023/A:1009738307837

[40] Murphy, J. and Riley, J.P. (1962) A Modified Single Solution Method for Determination of Phosphate in Natural Waters. *Analytica Chimica Acta*, **27**, 31-36. https://doi.org/10.1016/S0003-2670(00)88444-5

[41] Hansen, M.C., Stehman, S.V., Potapov, P.V., Loveland, T.R., Townshend, J.R., De Fries, R.S., Pittman, K.W., Arunarwati, B., Stolle, F., Steininger, M.K., Carroll, M. and DiMiceli, C. (2008) Humid Tropical Forest Clearing from 2000 to 2005 Quantified by Using Multitemporal and Multiresolution Remotely Sensed Data. *Proceedings of the National Academy of Sciences of the United States of America*, **105**, 9439-9444. https://doi.org/10.1073/pnas.0804042105

[42] De Moraes, R.M., Delitti, W.B.C. and Struffaldi-De Vuono, Y. (1999) Litterfall and Litter Nutrient Content in Two Brazilian Tropical Forests. *Brazilian Journal of Botany*, **22**, 9-16. https://doi.org/10.1590/S0100-84041999000100002

[43] Oseni, O.A., Ekperigin, M.M., Akindahunsi, A.A. and Oboh, G. (2007) Studies of Physiochemical and Microbial Properties of Soils from Rainforest and Plantation in Ondo State, Nigeria. *African Journal of Agricultural Research*, **2**, 605-609.

[44] Ghehi, N.G., Nemes, A., Verdoodt, A., Van Ranst, E., Cornelis, W.M. and Boeck, P. (2012) Nonparametric Techniques for Predicting Soil Bulk Density of Tropical Rainforest Topsoils in Rwanda. *Soil Science Society of America Journal*, **76**, 1172-1183. https://doi.org/10.2136/sssaj2011.0330

[45] Marques, M.C.M., Roper, J.J. and Salvalaggio, A.P.B. (2004) Phenological Patterns among Plant Life Forms in a Subtropical Forest in Southern Brazil. *Plant Ecology*, **173**, 203-213. https://doi.org/10.1023/B:VEGE.0000029325.85031.90

[46] Holland, J.E., White, P.J., Glendining, M.J., Goulding, K. and McGrath, S.P. (2019) Yield Responses of Arable Crops to Liming—An Evaluation of Relationships Between Yields and Soil pH from a Long-Term Liming Experiment. *European Journal of Agronomy*, **105**, 176-188. https://doi.org/10.1016/j.eja.2019.02.016

[47] Makate, C. and Makate, M. (2019) Interceding Role of Institutional Extension Services on the Livelihood Impacts of Drought Tolerant Maize Technology Adoption in Zimbabwe. *Technology in Society*, **56**, 126-133. https://doi.org/10.1016/j.techsoc.2018.09.011

[48] Fornara, D.A., Steinbeiss, S., McNamara, N.P., Gleixner, G., Oakley, S., Poulton, P.R., Macdonald, A.J. and Bardgett, R.D. (2011) Increases in Soil Organic Carbon Sequestration Can Reduce the Global Warming Potential of Long-Term Liming to Permanent Grassland. *Global Change Biology*, **17**, 1925-1934. https://doi.org/10.1111/j.1365-2486.2010.02328.x

[49] Shi, R.-Y., Liu, Z.-D., Li, Y., Jiang, T., Xu, M., Li, J.-Y. and Xu, R.-K. (2019) Mechanisms for Increasing Soil Resistance to Acidification by Long-Term Manure Application. *Soil and Tillage Research*, **185**, 77-84. https://doi.org/10.1016/j.still.2018.09.004

[50] Rahman, M.A., Lee, S.H., Ji, H.C., Kabir, A.H., Jones, C.S. and Lee, K.W. (2018) Importance of Mineral Nutrition for Mitigating Aluminum Toxicity in Plants on Acidic Soils: Current Status and Opportunities. *International Journal of Molecular Sciences*, **19**, 3073. https://doi.org/10.3390/ijms19103073