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Environmental impact of oil palm processing on some properties of the on-site soil in a growing city in Nigeria

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Both natural and anthropogenic activities exert a great influence on soil conditions, with some being beneficial to soil health. This study was conducted to assess the impact of oil palm processing activities on selected soil properties in Iwo, Nigeria. Soil samples taken from upstream, mid-section, and downstream points along an oil palm mill dumpsite were compared against a control. Soil organic matter, bulk density, and soil moisture were determined using standard procedures, while soil structural stability was estimated using stability index. The soil organic matter was significantly higher at the oil palm mill relative to the control and reduced by 50.8 and 64.4% at the upstream and downstream relative to the mid-section, respectively. The bulk density did not differ significantly among the sampling points but increased at the upstream, mid-section, and downstream by 2.4–13.1% compared with the control. The soil moisture at field capacity was substantially higher at the site relative to the control, with the upstream having the highest value (0.94 m^3m^{-3}). The soil structural stability was superior at the mid-section and reduced by 57.0–76.2% at the upstream, downstream, and control points. In general, oil palm mill processing activities improved the on-site soil organic matter and its physical conditions.

KEYWORDS

oil palm mill, soil health, human environment, sustainability, soil property

Introduction

The human environment is never known to be static as it undergoes various modifications by either natural or anthropogenic activities (Tilman and Lehman, 2001; Soga and Gaston, 2020). Such activities effect changes in the quality and integrity of natural environments that if not checkmated may aggravate untold negative impacts on human sustainability. For instance, erosion of different forms, especially from the source region, modifies the Earth surface such that the soil may become degraded for the use for agricultural purposes. However, the receiving region may encourage enrichment of the soil downstream. Apart from this, construction activities often lead to the removal of the rich top soil and tree-logging activities also expose soils, thus encouraging soil compaction. However, not all these modifications are avoidable in the light of request for development and urban expansion. Soil has been at the receiving end of the consequential implications of various anthropogenic activities. According to Garbuio et al. (2012), the impacts of human activities on soil contamination are many and varied. The extent of human impact has become so pervasive and profound that there is currently much discussion on a new geologic record called the "*anthropocene*" which is characterized by anthropogenic disturbances. Garbuio et al. (2012) further revealed that the effects of human activities vary with land use, ranging from agricultural wastes such as farm animal sewerage and fertilizer runoff to industrial and commercial wastes of every conceivable type and magnitude. In the same vein, Biyogue (2016) and Odekunle et al. (2020) in their separate investigations revealed that deforestation has implied effects on the soils when compared with the soil under forest. Both studies found that the bulk density, cation-exchange capacity (CEC), soil organic carbon, total nitrogen, and phosphorous values were higher in soils under forests than that under deforestation. However, investigation into what human activities contribute to the status of soils is salient to the understanding of this resource to ensure its appropriate use in space and time. Soils of good quality are required for result-oriented agricultural practices, while a low-quality one requires remediation. According to Tahat et al. (2020), good soil health is panacea to multiple ecosystem services such as water quality sustenance, the productivity of plants, control of soil nutrient recycling, decomposition, and enhancing the removal of greenhouse gases from the atmosphere. The study of soil health has always been in conjunction with sustainable agriculture since soil microorganism diversity and activity are integral part of soil health. Doran and Zeiss (2000) defined soil health as "the capacity of a soil to function as a vital living system within ecosystem and land use boundaries to sustain plant and animal production, maintain or enhance water and air quality, and promote plant and animal health". It was further reiterated that soil health is related to agricultural output and capacity to support wildlife, protect watershed, or provide recreational outputs. In another sense, Idowu et al. (2014) defined soil health as the state of being in sound physical, chemical, and biological conditions, having the capability to sustain the growth and development of plants.

Several factors determine soil health at any point in time and space; among these are human activities such as construction and industrial activities, agricultural activities, war, wildlife composition, and so on. Also, several natural phenomena could contribute to the health of soil, such as volcanicity, earthquake, weathering processes, and soil waste. The contribution of palm oil wastes to the on-site soil conditioning cannot be overlooked. Okereke and Ginikanwa (2020) noted that oil palm effluents increase soil acidity, thus hindering the efficacy of soil pH in plant growth. Okwute and Isu (2007a) had noted that plants thrive well within a pH range of 6.5–7.5. In another instance, Okwute and Isu (2007b), and Eze et al. (2013) revealed that palm oil effluents aggravate the content of organic carbon, total nitrogen, phosphate, sulfate, phosphorous, calcium, magnesium, aluminum, and hydrogen in the soil. However, due to the acidic effect on soils, some of these physico-chemical nutrients are hindered from being utilized optimally in plant growth. Furthermore, Okwute and Isu (2007b) and Ohimain et al. (2012) discovered that oil palm effluents increase the soil bulk density and percentage of silt and clay and also water retention due to the presence of unrecovered oil and debris generated during the processing. This research aims at assessing the impact of local oil palm activities on the on-site soil health with the intention to show its quality and relevance for human use. The specific aim is to determine the physical properties of the on-site soil in the local oil palm processing center.

Materials and methods

Study area

This study was carried out in Iwo (7° 38′ N and 4° 11′ E), the headquarters of Iwo Local Government Area of Osun State, Nigeria. Iwo has an area of 245 km^2 with a population of 191,348 according to 2006 Nigeria Population Census. The prevailing climatic condition is tropical with about 8 months of rainfall (March to October) and about 4 months of dry season (November to February). Iwo is an agrarian economy, with its inhabitants depending primarily on crop farming, animal slaughtering, lumbering, fishing, and oil palm milling among others for livelihood. Although there are other secondary and tertiary activities in the town, these represent a negligible proportion among the populace. Oil palm tree is one of the invasive and dominantly found plants in Iwo and its environs. Plantation of oil palm is found in most cocoa farms apart from other modern plantations owned by both indigenes and non-indigenes. The prevalence of oil palm processing in Iwo has been further encouraged by government policies, through soft loans, for the establishment of local mills, mechanization of the processing activities, and an improved pricing system, among others. Thus, local oil mills are found in the nooks and crannies of Iwo. For instance, there are several oil palm mills along Aiba downstream, including Aiba oil mills (*Ebu Aiba*), Alawe

10.3389/fenvs.2022.918478

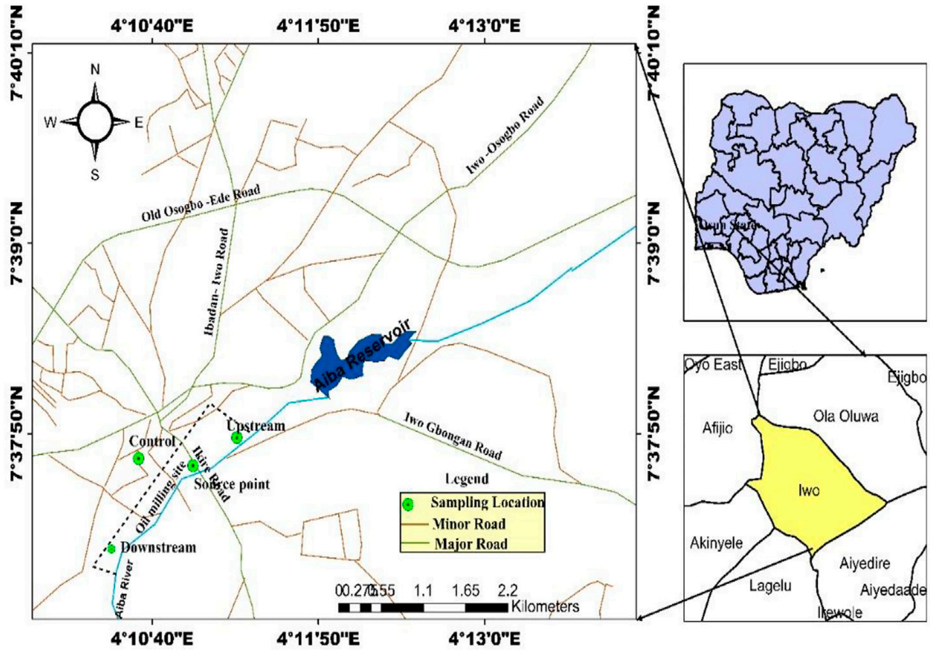

FIGURE 1
Map showing the study site in Iwo, Osun State, Nigeria.

mills (*Ebu Alawe*), and Ayewa oil mills (*Ebu Ayewa*), among others. Aiba oil mills were chosen for this study because they are located along the Aiba River channel within the township of Iwo (Figure 1). Apart from this, the Aiba oil mill happens to be one of the biggest oil palm mills in Iwo and is located within the area where farming is carried out, especially during the dry season.

Soil Sampling and analysis

Soil samples were taken at 0–15 cm depth using a soil auger and core samplers (5 × 5 cm) at both the control points (100 m from the mill) and three points (upstream, mid-section, and downstream) along the toposequence of the dumpsite of the mill. Triplicate samples were collected and taken to the laboratory for processing and analysis of some selected soil properties. The soil organic matter was estimated by determining the soil organic carbon content using the loss-on-ignition procedure (Cambardella et al., 2001) and multiplying by the van Bemmelen factor (1.724). Bulk density was determined using the core procedure, while total porosity was estimated from the bulk density value as described by Grossman and Reinsch (2002). Soil moisture at field capacity was estimated using the procedure given by Reynolds et al. (2009), while particle size distribution was determined by the hydrometer method as described by Gee and Or (2002). The soil structural stability index (S) was estimated using the equation described by Pieri (1989) below.

$$S = \frac{Organic\ Matter\ Content\,(\%)}{Clay\,(\%) + Silt\,(\%)} \times \frac{100}{1}$$

Data analysis

All data generated from the study were subjected to descriptive statistics and analysis of variance, while means that were significantly different were further grouped using the Duncan multiple range test. All statistical analyses were performed using GenStat Discovery Edition 8.1, and the level of significance was set at 5%.

Results

The average soil organic matter content of each sampled point along the toposequence is presented in Figure 2. There was a significant ($p < 0.05$) difference in soil organic matter along the toposequence, with the mid-stream having the highest value (5.9 g kg^{-1}). However, it reduced by 50.8% and 64.4% at the upstream and downstream points, respectively. Although, the lowest organic matter content

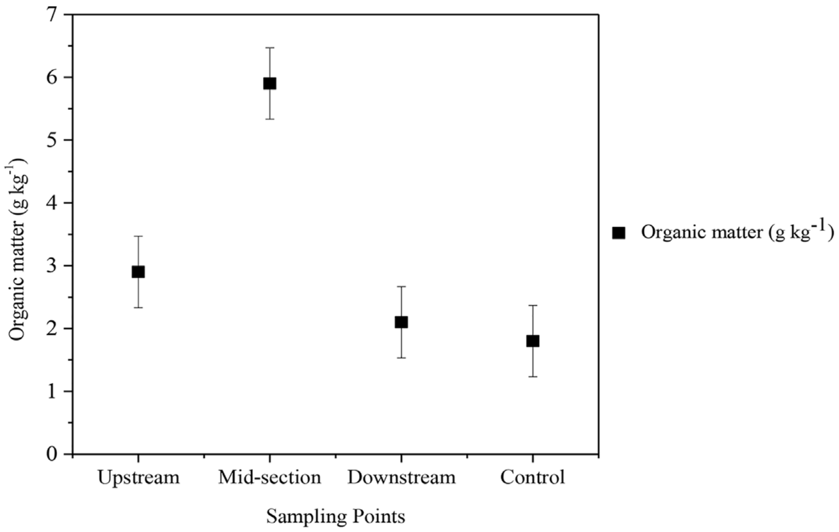

FIGURE 2
Organic matter content of soils along sampling points of a toposequence.

TABLE 1 Soil physical properties of three sampling points along the toposequence of an oil palm mill site.

Sampling points	Sand	Silt	Clay	ρ_b (Mg m^{-3})	P_T (%)	Θ_{FC} (m^3 m^{-3})	S
	g kg^{-1}						
Upstream	560.7 ± 62.90 ab	250.0 ± 34.00a	189.3 ± 0.90d	0.88 ± 0.23	66.8 ± 4.10	0.94 ± 0.05a	0.65 ± 0.11b
Mid-section	611.1 ± 10.50a	178.0 ± 12.10b	210.9 ± 1.60c	0.95 ± 0.17	64.2 ± 3.40	0.70 ± 0.16b	1.51 ± 0.10a
Downstream	504.5 ± 16.20b	200.0 ± 10.60b	295.5 ± 7.10b	0.86 ± 0.10	67.5 ± 3.70	0.88 ± 0.12 ab	0.42 ± 0.03c
Control	498.0 ± 44.40b	95.5 ± 5.80c	406.5 ± 5.70a	0.84 ± 0.05	68.3 ± 2.10	0.69 ± 0.04b	0.36 ± 0.07c
$S.E.D_{(0.05)}$	32.40	15.54	3.79	Ns	Ns	0.09	0.07

Values are mean ± standard deviation; means with the same letter(s) are not significantly different at $p < 0.05$; ρ_b is the soil bulk density; Θ_{FC} is the soil moisture content at field capacity; S is the soil structural stability index, and $S.E.D_{(0.05)}$ is the standard error of differences of means at 5% probability.

was found in the control point, it was statistically comparable with upstream and downstream points. Table 1 presents the results of the soil physical properties of the sampling points along the toposequence of the oil palm mill site. Regarding soil separates, the sand content was consistently higher than silt and clay in all the sampling points and was more in the upstream, mid-section, and downstream by 12.6%, 22.7%, and 1.3% relative to the control, respectively. Further, there was a significant ($p < 0.05$) difference in the silt content among the sampling points. In comparison, the control point had the lowest silt content (95.5 g kg^{-1}), while the upstream, mid-section, and downstream of the oil palm mill site were higher by 86.4–161.8%. Conversely, the control point had the highest clay content (406.5 g kg^{-1}), and this significantly ($p < 0.05$) reduced by 53.4–27.3% at the upstream, mid-section, and downstream points. The bulk density was the highest at the mid-section but did not differ significantly ($p < 0.05$) among the sampling points. Comparatively, it was higher by 2.4–13.1% at the upstream, mid-section, and downstream than the control point. Similarly, there was no significant ($p < 0.05$) difference in total porosity among the sampling points. Moreover, the highest value was recorded in the control point (68.3%), and this reduced by 1.2–6.0% in the upstream, mid-section, and downstream. Considering field capacity, there was 1.4–36.2% significant increase in all sampling points along the oil palm mill site relative to the control, with the upstream having the highest value (0.94 m^3 m^{-3}). However, this reduced by 25.5% and 6.4% at the mid-section and downstream points, respectively. Soil structural stability was superior at the mid-section but was substantially lower by 57.0–76.2% at the upstream, downstream, and control points. It is worthy to note that the control point and downstream did not differ significantly ($p < 0.05$) in soil structural stability.

Discussion

Soil organic matter was generally low in all the sampled points and was markedly below the critical limit of the Federal Ministry of Agriculture and Water Resources and Rural Development (2011). This is symbolic of low soil quality in the study area. Furthermore, the difference in soil organic matter content along the toposequence is indicative of variation in anthropogenic activities and land use impacts. The high organic matter content at the mid-section, relative to the upstream, downstream, and control points could be due to a high amount of deposition and decomposition of organic materials in this area. In addition, the vicissitude in climate effect could also affect the rate of weathering, thereby leading to differences in organic matter content. This result is in consonance with the findings of Aliku and Oshunsanya (2018), who reported a high organic matter content at upper soil layers relative to subsoil layers in a similar agro-ecological zone. They attributed their result to the influence of temperature and precipitation on weathering of parent materials and decomposition of plant litter, which ultimately affect soil mineral and organic matter content.

Furthermore, the dominance of sand fraction across the sampling points could be due to their similarity in parent material. Babalola et al. (2000) earlier reported that soils in this location are formed from the coastal plain sands. Contrary to the reports of Aliku and Oshunsanya (2018), the clay content observed in this study increased down the slope. This could be ascribed to clay movement by eluviation, especially by water, wind, and tillage erosion. The superior clay content in the control could be credited to a higher rate of weathering relative to the other sampled points. The trend in particle size distribution observed in the control point is similar to the results of Aiyelari et al. (2019) and Aliku et al. (2021). Although the bulk density was generally low in all the sampled points, the superior value obtained at the mid-section relative to the upstream and downstream could be due to its superior organic matter and high sand contents. This also explains the low bulk density and the high clay content in the control. This result reflects a higher level of soil compaction at the mid-section compared with the upstream and downstream points, respectively. The relationship between bulk density and soil compaction has earlier been reported (Mamman and Ohu, 1997; Aliku et al., 2019; Yu et al., 2019). While high soil compaction could inhibit crop growth and root development (Mamman and Ohu, 1997), it has also been shown to impede the process of soil erosion by resulting in more stable surface soil structures (Yu et al., 2019). In addition, the superior total porosity observed in the control point relative to the upstream, mid-section, and downstream could be credited to a high clay content. This is due to the fineness and the large surface area of clay-sized particles. Oshunsanya and Aliku (2016) explained that particles with a large surface area increase soil micro- and meso-pores at the expense of macro-pores, thereby increasing soil porosity. The superior soil moisture at field capacity in the upstream, mid-section, and downstream, relative to the control, could be due to their superior organic matter content. This is because organic matter has high affinity for water, thus increasing the water-holding capacity of soil (Aliku et al., 2019). Similarly, some authors earlier explained that the hydrophilic nature of organic matter results in an improvement in soil moisture retention (Rawls et al., 2003; Huntington, 2007; Aliku and Oshunsanya, 2018). In addition, the superior structural stability in the mid-section is a reflection of the impact of its superior organic matter content on soil aggregation and aggregate stability. This result is in line with the findings of several authors (Huntington, 2007; Aliku et al., 2019) who reported that organic matter enhances the soil structure. Our results show that the structural stability index was generally low (below 5) across all the sampled points, indicating a severely degraded soil physical health condition. Hence, the soil in the study area would require high organic matter input and good soil management practices for restoration for optimum crop production.

Conclusion and recommendation

Oil palm processing activities had positive effects on the properties of the soil in the study area. Soil organic matter was substantially increased at the oil palm mill site and was superior at the mid-section. The bulk density was also higher at the upstream, mid-section, and downstream, making the soil more compact and stable at the oil palm mill site relative to the control point. Furthermore, total porosity and soil moisture were improved by oil palm mill processing activities relative to the control site. This could be beneficial for improved crop growth and yield. Accordingly, soil structural stability was enhanced at the oil palm mill site, being superior at the mid-section compared with the control. Our results show that oil palm mill processing activities can improve the organic matter content and physical properties of soils. In general, the mid-section of the oil palm mill site was much improved than the other points along the toposequence and could be beneficial for sustainable crop production.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material; further inquiries can be directed to the corresponding author.

Author contributions

OT designed the project, carried out literature review and the methodology and supervised the work, wrote the first draft together with AO, and proofread the manuscript. AO wrote the results and the discussion section of the project, wrote the abstract, and proofread the draft. OP worked on the field activities and read through the script. OI proofread the script and was involved in the laboratory activities. AV worked on the map used as a GIS expert together with OT, and AE did the laboratory analysis of the soil samples.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Aiyelari, E. A., Oshunsanya, S. O., Aliku, O., and Akomolafe, T. N. (2019). Energy requirement for manual cassava harvesting on coarse textured soils in Ibadan, Nigeria. *J. Agric. Sci. Technol.* 21 (2), 439–450.

Aliku, O., and Oshunsanya, S. O. (2018). Assessment of the SOILWAT model for predicting soil hydro-physical characteristics in three agro-ecological zones in Nigeria. *Int. Soil Water Conserv. Res.* 6, 131–142. doi:10.1016/j.iswcr.2018.01.003

Aliku, O., Oshunsanya, S. O., and Ikoko, C. B. (2019). Organic farming: An agricultural waste management system for enhancing soil properties and crop yield. Modern. *Concepts Dev. Agron.* 4 (5), 478–482.

Aliku, C. B., Madu, C. N., and Aliku, O. (2021). Organic stimulants for enhancing phytoremediation of crude oil polluted soil: A study on cowpea. *Environ. Pollut.* 287, 117674. doi:10.1016/j.envpol.2021.117674

Babalola, O., Zagal, E., and Ogunsola, O. (2000). "Physical conditions and degradation of Nigerian soils," in Proceedings of the 26th annual conference of soil science society of Nigeria, 96–111.

Biyogue, D. N. (2016). Impacts of anthropogenic activities on physical and selected chemical properties of soils in the natural forest→savanna of Northern Ghana. *J. Soil Sci. Environ. Manage.* 7 (5), 53–63. doi:10.5897/JSSEM2015.0542

Cambardella, C. A., Gajda, A. M., Doran, J. W., Wienhold, B. J., and Kettler, T. A. (2001). "Estimation of particulate and total organic matter by weight loss-on-ignition," in *Assessment methods for soil carbon*. Editors R. Lal, J. M. Kimbe, R. F. Follet, and B. A. Stewart (Boca Raton (FL): Lewis Publishers), 349–359.

Doran, J. N., and Zeiss, M. R. (2000). Soil health and sustainability: Managing the biotic component of soil quality. *Appl. Soil Ecol.* 15, 3–11. doi:10.1016/s0929-1393(00)00067-6

Eze, V. C., Owunna, N. D., and Avoaja, D. A. (2013). Microbiological and Physico-Chemical characteristics of soil receiving palm oil mill effluents in Umuahia, Abia State, Nigeria. *J. Nat. Sci. Res.* 3, 163–169.

Federal Ministry of Agriculture; Water Resources and Rural Development (2011). *Fertilizer use and management practices for crops in Nigeria*. Technical Bulletin Series No. 2.

Garbuio, F. J., Howard, J. L., and dos Santos, L. M. (2012). Impact of human activities on soil contamination. *Appl. Environ. Soil Sci.* 2012, 1–2. doi:10.1155/2012/619548

Gee, G. W., and Or, D. (2002). "Particle-size analysis," in *Methods of soil analysis. Part 4. Physical methods*. Editors J. H. Dane and G. C. Topp (Madison (WI): Soil Science Society of America), 255–294.

Grossman, R. B., and Reinsch, T. G. (2002). "Bulk density and linear extensibility: Core method," in *Methods of soil analysis. Part 4. Physical methods*. Editors J. H. Dane and G. C. Topp (Madison (WI): Soil Science Society of America), 208–228.

Huntington, T. G. (2007). "Available water capacity and soil organic matter," in *Encyclopedia of soil science*. second ed. (New York: Taylor & Francis), 139–143.

Idowu, J., Ghimire, R., Flynn, N., and Gangali, A. (2014). *Soil health-importance, assessment and management, Cooperative Extension Services*. Las Cruces, New Mexico: New Mexico State University. Circular 694B.

Mamman, E., and Ohu, J. O. (1997). Millet yield as affected by tractor traffic in a sandy loam soil in Borno State, Nigeria. *Soil Tillage Res.* 42, 133–140. doi:10.1016/s0167-1987(96)01089-6

Odekunle, O., Ogunbode, T. O., and Ogungbile, P. O. (2020). Comparative Analysis of the top soil properties under forested and deforested zones: implications for the environment. *Int. J. Environ. Clim. Change* 10 (1), 19–25. doi:10.9734/ijecc/2020/v10i130171

Ohimain, E. I., Daokoru-Olukole, C., Izah, S. C., Eke, R. A., and Okonkwo, A. C. (2012). Microbiology of palm oil mill effluents. *J. Microbiol. Biotechnol. Res.* 2 (6), 852–857. doi:10.22192/ijarbs

Okereke, J. N., and Ginikanwa, R. C. (2020). Environmental impacts of palm oil effluents and its management through biotechnological approaches. *Int. J. Adv. Res. Biol. Sci.* 7 (7), 117–127.

Okwute, O. L., and Isu, N. R. (2007a). Impact analysis of palm oil mill effluent on the aerobic bacterial density and ammonium oxidizers in a dumpsite in Anyigba, Kogi State. *Afr. J. Biotech.* 6 (2), 116–119.

Okwute, O. L., and Isu, N. R. (2007b). The environmental impact of palm oil mill effluent (POME) on some physico-chemical parameters and total aerobic, bioload of soil at a dumpsite in Anyigba, Kogi State, Nigeria. *Afr. J. Agric. Res.* 2 (12), 656–662.

Oshunsanya, S. O., and Aliku, O. (2016). "Biochar technology for sustainable organic farming," in *Organic farming – a promising way of food production*, 112–129. 978-953-51-4582-0. Chapter 6. doi:10.5772/61440

Pieri, C. (1989). *Fertilité des terres de savane. Bilan de trente ans de recherche et de développement agricoles au sud du Sahara*. Paris: Ministère de la Coopération Kirad, 444.

Rawls, W. J., Pachepsky, Y. A., Ritchie, J. C., Sobecki, T. M., and Bloodworth, H. (2003). Effect of soil organic carbon on soil water retention. *Geoderma* 116 (1–2), 61–76. doi:10.1016/s0016-7061(03)00094-6

Reynolds, W. D., Drury, C. F., Tan, C. S., Fox, C. A., and Yang, X. M. (2009). Use of indicators and pore volume-function characteristics to quantify soil physical quality. *Geoderma* 152, 252–263. doi:10.1016/j.geoderma.2009.06.009

Soga, M., and Gaston, K. J. (2020). The ecology of human-nature interactions. *Proc. R. Soc. B* 287, 20191882. doi:10.1098/rspb.2019.1882

Tahat, M. M., Alananbeh, K. M., Othman, Y. A., and Leskovar, D. I. (2020). Soil health and sustainable Agriculture. *Sustainability* 12, 4859. doi:10.3390/su12124859

Tilman, D., and Lehman, C. (2001). Human-caused environmental change: Impacts on plant diversity and evolution. *Proc. Natl. Acad. Sci. U. S. A.* 98 (10), 5433–5440. doi:10.1073/pnas.091093198

Yu, H., Li, Y., Oshunsanya, S. O., Are, K. S., Geng, Y., Saggar, S., et al. (2019). Re-introduction of light grazing reduces soil erosion and soil respiration in a converted grassland on the Loess Plateau, China. *Agric. Ecosyst. Environ.* 280, 43–52. doi:10.1016/j.agee.2019.04.020