Overlooked Influence of Indian Hemp (*Cannabis sativa*) Cultivation on Soil Physicochemical Fertility of Humid Tropical Agroecosystems: Lowland Soils

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Abstract

One agricultural practice that may be depleting plant nutrients in wetland soils of the humid tropics is cultivation of Indian hemp (*Cannabis sativa*), also called *Marijuana*. Though Nigerian Law, adopted from International Conventions on narcotics, prohibits handling of any part of *cannabis* plant, it is still illicitly cultivated. This practice may be undermining the quality of wetland agroecosystems. To support these concerns with empirical data, the influence of *Cannabis* cultivation on soil physicochemical fertility of wetland agroecosystems was assessed at a representative location in southwestern Nigeria. The study compared four land-use options; land not used for *Cannabis* cultivation (NUC), land currently under *Cannabis* cultivation (CCC), farmlands converted from *Cannabis* to alternative use (CAU), and *Cannabis* farmlands abandoned or seized (ABS). Soil data from the pedogenetic horizons under these land-use options were averaged and analysed. There were significant differences in soil bulk density, with low values in NUC (1.36 Mg m^{-3}) < medium values in CCC (1.55 Mg m^{-3}) < high values in both CAU and ABS (1.62-1.66 Mg m^{-3}). The highest value in the ABS (1.66 Mg m^{-3}) is slightly above the critical limit (1.60 Mg m^{-3}) for root growth. Soil compaction in *Cannabis* farmland thus worsened even after discontinuation of cultivation. Soil pH, soil organic C, total N, exchangeable Ca, exchangeable Mg, apparent and effective cation exchange capacity also differed thus NUC ≥ CCC ≥ CAU ≥ ABS, while base saturation showed an inverse trend. Available P was, however, higher in CCC (14.32 mg kg^{-1}) than the rest, with lowest values in ABS (5.83 mg kg^{-1}). Micronutrients (Mn, Zn and Cu), excluding Fe which was unaffected, followed the trend of soil pH. It is concluded that continuous cultivation of *Cannabis* in humid tropical lowlands compacts the soil and drains soil nutrients except available P whose status is rather elevated. The practice thus poses a threat to food security and ecological well-being.

Keywords: narcotic vegetable, land-use options, residue removal, nutrient mining, soil quality

Introduction

Indian hemp (*Cannabis sativa*), also called *Marijuana*, is a narcotic vegetable plant grown clandestinely primarily for smoking of the leaves. It is locally known as '*igbo*', '*ganja*', '*stone*', '*morocco*', '*weed*', 'smoke', etc. (Kolo, 2019). Substantial amounts of illicit *Cannabis* from Nigeria are trafficked into the black markets of the United States of America, Europe and some Asian countries (Kolo, 2019). Many industrialized nations licitly grow *Cannabis* in controlled quantities for its roots, stems, leaves, flowers and the seeds for recreational, medicinal and industrial purposes (Deus Ventures Official, 2020).

Cannabis roots grow extensively in the soil, as they mine water and nutrients (Bergman, 2011). The high demand for the leaves of *Cannabis* and other parts of the plant means that its cultivation involves complete harvesting and no returning of crop residues to the soil, a situation that may alter nutrient recycling processes (Kolo, 2019). Continuous illicit cultivation of *Cannabis* with poor soil and water management practices can thus potentially drain the soil of its nutrient reserves. This situation poses serious danger to soil quality and could diminish the agricultural potential of the soil (Shaver et al., 2002; Igwe, 2003; Blanco-Conqui and Lal, 2009; Smith et al., 2012; Van-Donk et al., 2012).

In some parts of southwestern Nigeria, uplands and lowlands (wetlands) are cultivated to *Cannabis* in alternate rainy and dry seasons, respectively (Kolo, 2019). Illicit *Cannabis* farmers take advantage of nutrient status and residual moisture content in Aquic soils in the lowland topographic positions for dry season farming. Lowland ecosystems have potential for all-season agricultural production (Singh, 1997; Wakatsuki et al., 2011, 2014). When put to proper use, lowlands can enhance food production substantially in the long term (Adigbo et al., 2011; Nosiru et al., 2012; Omara-Achong et al., 2012; Obalum et al., 2012a; Adekayode, 2014; Ukabiala et al., 2021).

In spite of the existential threat to food production in Nigeria in the face of the rapid growth in population (Windmeijer and Andriesse, 1993), a cartel of wealthy drug barons invests heavily in the illicit cultivation of *Cannabis*. Provisions of the law to confiscate lands used for *Cannabis* cultivation among other penalties appear not to be a deterrent. In 2013 and 2014, about 850 and 4,500 ha, respectively of illicit *Cannabis* fields were traced and destroyed mostly in Southwestern Nigeria (Giade, 2014; NDLEA, 2015). These figures represent an increase of 434.43% in 2014 over 2013. After 2014, logistics and financial resources to trace and destroy illicit *Cannabis* fields by the National Drug Law Enforcement Agency (NDLEA) became increasingly scarce (Kolo, 2019), and so more cultivated fields remained untraceable. Motivated by the prospect of huge monetary profits from illicit trade and inadequacy of effective control measures, many smallholder rural farmers may begin to engage in the illicit cultivation of this crop.

Cannabis cultivation drains the soil nutrients and so poses a serious threat to food security (Bergman, 2011; Fagge, 2014; NDLEA, 2015). Illicit cultivation of *Cannabis* will, therefore, not only add to the existing pressure on agricultural soils due to the ever-expanding rate of urbanization in Nigeria, but may also contribute to undermining soil physicochemical fertility, resulting in further shrinkage in food production. Because *Cannabis* consumption endangers human health, the counting the losses due to illicit *Cannabis* cultivation should not leave out its impact on the labour force and hence overall productivity of the country's productivity.

There is a paucity of field-based data on the influence of illicit *Cannabis sativa* cultivation on soil properties, mostly due to security and safety concerns for researchers within and around these farmlands and the host communities. A sizable area of land is under illicit *Cannabis* in Southwestern Nigeria. A soil-based investigation into this practice could, therefore, help to provide data on any adverse effects in the soils, towards retrieving the affected lands and putting them to specific better and legitimate alternative uses. In this study, four land-use options identified as differing in cultivation status of *Cannabis* in the lowland topographic position were sampled along the soil profiles, considering the extensive root growth of this plant. The aim was to determine the influence of illicit *Cannabis* cultivation on physicochemical fertility indices of the lowland soils.

Materials and Methods

Study Area

One of the areas where large-scale illicit *Cannabis sativa* fields are found is Akure North Local Government Area of Ondo State in Southwestern Nigeria. This area is located

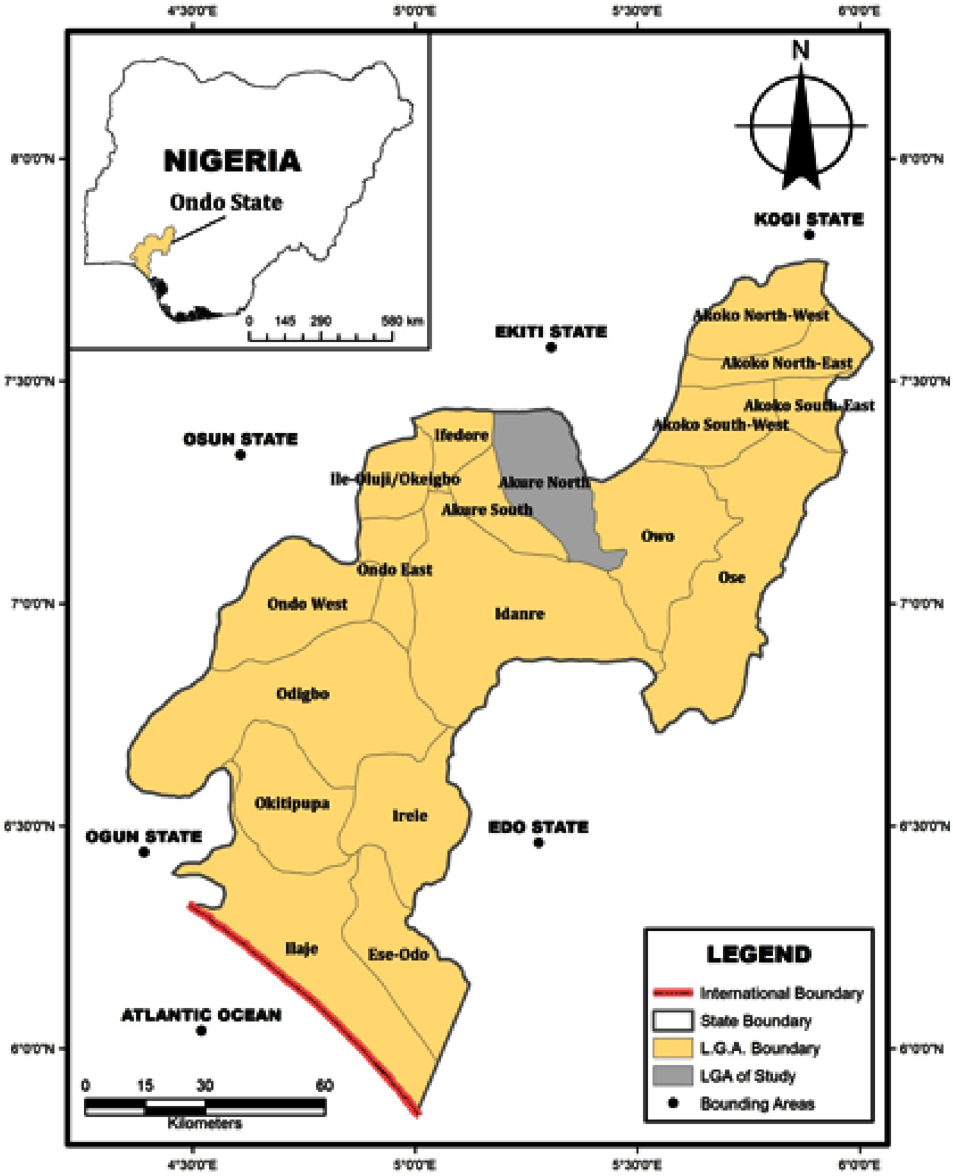

Figure 1 Map of Ondo State showing the local government area of study (Inset: Map of Nigeria)

at $7^0$25’30”N, $5^0$10’0”E and $7^0$5’35”N, $5^0$28’30”E (Fig. 1). The study units are at an altitude of approximately 300 m above sea level. The climate is humid tropical, with an average annual rainfall exceeding 2000 mm (Anifowose, 1989; Ajayi et al., 2012). Mean annual air temperature is 24.8^{o}C with relative humidity of 75.4% (Kolo, 2019). The parent material is Precambrian basement complex rock (Mogaji et al., 2011). The predominantly sandy clay loam and poorly drained soils of the study units were classified, according to Soil Taxonomy (Soil Survey Staff, 2014), as *Kandiaqualfs* (Kolo, 2019). The vegetation is a mix of natural and reserved forests. The natural and reserved forests in this area are characterized by the following tree species: *Melicia excelsa*, *Antaris africana*, *Terminalia superba*, *Lophira procera*, *Symphonia globulifera*, *Blighia sapida*, *Parkia biglobosa*, *Gmelina arborea* and *Tectona grandis*. Legitimate land use of the wetlands is mainly cultivation of rainfed rice with larger areas reserved for illicit *Cannabis* when the flood recedes. Observations during the field studies show that most recent practice at the wetlands is intercropping of maize and *Cannabis*. Illicit *Cannabis* farmlands are often abandoned after about four years of exhaustive use.

Field and Analytical Procedures

The wetlands in four non-contiguous communities known for illicit *Cannabis* cultivation in Akure Area of southwestern

Nigeria were identified (Fig. 2). In these communities, four land-use options were identified and investigated viz land not used for *Cannabis* cultivation (NUC), land currently under *Cannabis* cultivation (CCC), farmlands previously under *Cannabis* but now converted from *Cannabis* to alternative use (CAU), and farmlands previously under *Cannabis* but now abandoned or seized (ABS). Satellite imagery was used as a guide to identify the wetlands; the sampled land-use options on elevations in the range of 300-320 m asl were selected using free survey technique (Fig. 2). Just before the study, the NUC had been under legitimate agricultural cultivation for 15-20 years, while CCC had been under *Cannabis* cultivation for 4-5 years before being discovered by the Law Enforcement Agency (NDLEA) and used for this study. Both CAU and ABS were previously used for *Cannabis* for 3-6 years and, after exhaustive use and/or discovery by law enforcement agents, experienced a change in land use; CAU was converted to alternative use and had been under this alternative cultivation for 3-5 years, while ABS had been abandoned for a minimum of three years.

The information on the land use history of the sampled soil units were obtained through the NDLEA from recruited private agents who are natives and conversant with the agricultural practices in the local environment. Local communities and farmlands were accessed

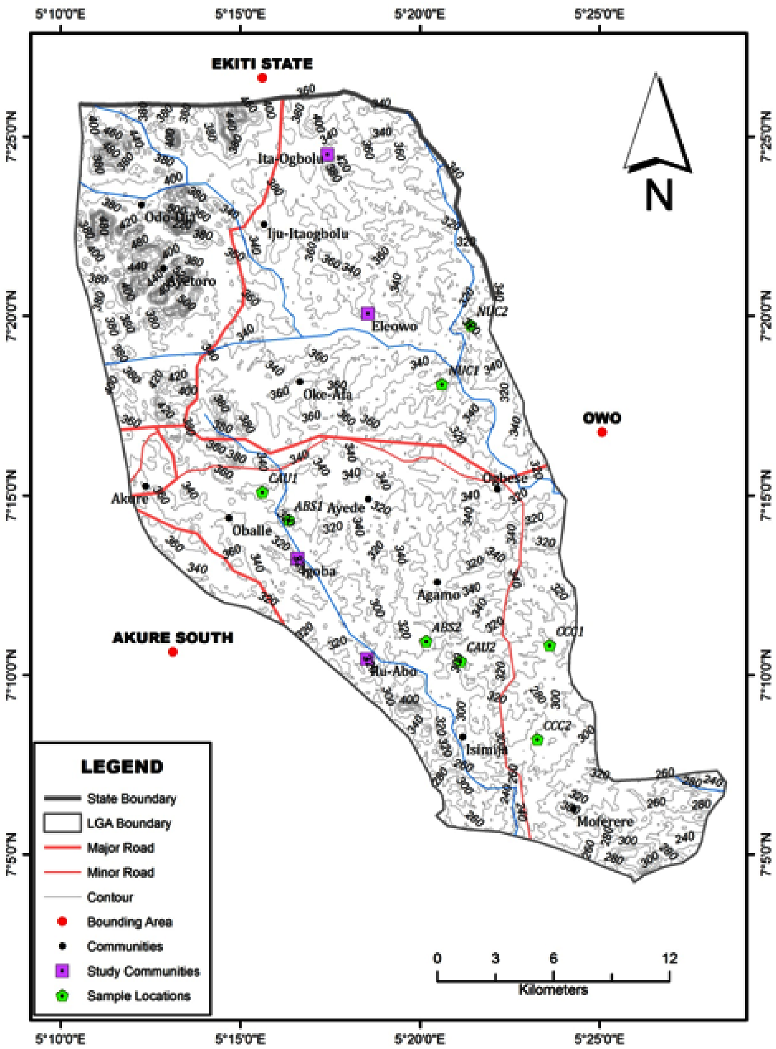

Figure 2 Contour/topographic map of Akure North Local Government Area, Ondo State of Nigeria showing local communities and sample locations at the lowland topographic setting (300-320 m asl)
NUC - land not used for Cannabis cultivation,
CCC - land currently under Cannabis cultivation,
CAU - farmlands converted from Cannabis to alternative use,
ABS - Cannabis farmlands abandoned or seized

through subterfuge which included hiding real identities of the researchers for personal safety, supported with the presence of armed guards during sampling especially at the CCC. Because of the extensive rooting system of *Cannabis* (Bergman, 2011) and the need to approach soil health cum fertility holistically with a view to accommodating every possible intended alternative land use, we involved the entire soil profile in the comparison of the land-use options. Eight soil profile pits were dug, two per land-use option. The pits were sited strategically to adequately represent the land-use options. The pedons were 71-150 m deep, with number of pedogenetic horizons varying between three and four. Undisturbed and disturbed soil samples were collected in triplicates from these pedogenetic horizons. The undisturbed samples were used to determine the hydraulic properties of the soils, while the disturbed samples were air-dried and then sieved through a 2-mm mesh for other soil physicochemical analyses.

Using the undisturbed soils (dimension, 5 cm × 5 cm), saturated hydraulic conductivity was determined by the constant head permeameter method of Klute and Dirksen (1986), and was calculated using the transposed Darcy's equation for vertical flows of liquids as:

$$K_s = (Q/At)\ (L/\Delta H)$$

where K_s is the saturated hydraulic conductivity (cm h^{-1}), Q is the steady state volume of outflow from the entire soil column (cm^3), A is the cross-sectional area of the sample (cm^2), t is the time interval of the water flow (h), L is the length of the sample (cm) and ΔH is the change in the hydraulic head (cm).

Thereafter, soil bulk density was determined by the core method (Blake and Hartge, 1986). Soil total porosity was calculated as the proportional volume not occupied by the solid phase of the soil (Obalum and Obi, 2014), computed as the ratio of bulk density to an assumed particle density (2.65 Mg m^{-3}).

Particle size distribution was determined by the hydrometer method (Gee and Or, 2002). Soil pH was determined in both distilled water and 0.1N KCl solution using a soil-solution ratio of 1:2.5 with a glass electrode pH meter (McLean, 1982). Soil organic carbon was determined using finely ground soil samples by the modified Walkley-Black wet digestion-oxidation method (Nelson and Sommers, 1996). Total N was determined using the micro Kjeldahl digestion-distillation method (Bremner, 1996). The available P was extracted with Bray No. 2, and determined by the procedure of Olsen and Sommers (1982). The exchangeable bases (K^+, Ca^{2+}, Mg^{2+} and Na^+) were extracted by leaching the soil at its own pH using ammonium acetate (NH_4OAc) solution after neutralizing this reagent (pH 7) to standardize the analysis. The K^+ and Na^+ in the extract were determined using a flame photometer while Ca^{2+} and Mg^{2+} were determined by EDTA titration (Udo et al., 2009); exchangeable acidity was determined using the titration method after extraction with 1.0M KCl (McLean, 1982). Thereafter, apparent cation exchange capacity (CEC) was determined on the soil leached with buffered NH_4OAc (pH 7) by titration following the procedure described by Rhoades (1982). The effective CEC (ECEC) was calculated as the summation of the exchangeable bases and the exchangeable acidity as extracted from the soil at its own pH. Base saturation of the soil's exchange site was, however, calculated as:

$$\%\ \text{Base saturation} = (\text{Total exchangeable bases} / \text{CEC}) \times 100$$

Some micronutrients including iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu) were extracted using a 0.1M HCl solution and determined on an Atomic Absorption Spectrophotometer at appropriate wavelengths (Lindsay and Norvell, 1978).

Statistical Analysis

To analyse the data, the average values of the soil parameters in the pedogenetic horizons were computed for each of the three replicate samples in a pedon; so there were six average values for the two pedons in a land-use option. These six means were regarded as replications to test the four land-use options for differences. This was done by applying ANOVA on the data using the software GenStat (Discovery

Edition 4), by the procedure suitable for the study design. Where the land-use options differed significantly ($P < 0.05$), inference was made by relating the means of any two of them to the least significant difference (LSD) value.

Results and Discussion

Particle Size Distribution of the Lowland Soils under the Four Land-Use Options

Table 1 shows the particle size distribution of the lowland soils under the four land-use options. Clay and fine sand were significantly higher in the NUC than the CCC, CAU and ABS. Silt was highest in the CAU and lowest in the CCC soils which showed higher coarse sand content than the rest. These variations in particle size distribution of the soils may not have been influenced by land-use option. Some findings indicated that such an index soil physical property as soil texture rarely changes with land use or changes in soil chemical composition (Igwe, 2001; Dawes and Goonetilleke, 2004). Tropical lowland ecosystems can show differences in particle size distribution and soil texture in accordance with the prevailing landforms and slopes (Obalum et al., 2011a). The possibility for variations in soil texture due to wide differences in vegetation types and ages may also not be the case in the present study; instead, it is the loosening of the topsoil associated with continuous tillage and the preferential removal of finer particles by overland flow that may be implicated (Oguike et al., 2022).

Influence of Land-Use Option on Some Hydraulic Properties of the Lowland Soils

Some hydraulic properties of the soils are also shown in Table 1. Soil bulk density showed lowest and highest values in the NUC and ABS, respectively. The reverse was the case for soil total porosity, being a derivative of bulk density. Complete removal of crop residue leads to a reduction in soil organic C and hence increases in soil bulk density (Shaver et al., 2002). As will be shown shortly, the NUC had the highest soil organic C, understandably because this land-use option did not entail complete removal of crop residue from the field. Besides increases in soil organic C, retention of crop residue in the field is one way to minimize increases in compaction due to traffic and heavy raindrop impact in the tropics. To this effect, the lower soil bulk density in the NUC despite its high fine sand content compared with the rest is attributed to the high clay and organic C contents in this farmland (Babalola and Ogban, 2003; Kolo et al., 2009; Obalum et al., 2011b). Notably, the bulk density values in CAU and ABS were above 1.60 Mg m^{-3} regarded as the critical limit for root growth (NSSC, 1995).

The saturated hydraulic conductivity (K_s) did not vary significantly among the four land-use options studied. This is in spite of the differences in soil bulk density and total porosity, high values of the latter of

TABLE 1

Influence of land-use option on some physical and hydraulic properties at the lowland topographic positions in Akure area of southwestern Nigeria

Land-use option	Clay	Silt	Fine sand	Coarse sand	BD	%	Ks
	(g kg^{-1})				(Mg m^{-3})	TP	(cm h^{-1})
NUC	186	125	376	313	1.36	48.65	4.62
CCC	133	120	301	446	1.55	41.48	2.78
CAU	145	182	348	325	1.62	38.87	7.60
ABS	138	165	317	358	1.66	37.36	5.03
$LSD_{(0.05)}$	40	50	70	50	0.11	6.90	NS

NUC - land not used for Cannabis cultivation, CCC - land currently under Cannabis cultivation,
CAU - farmlands converted from Cannabis to alternative use, ABS - Cannabis farmlands abandoned or seized;
BD - bulk density, TP - total porosity, Ks - saturated hydraulic conductivity,
$LSD_{(0.05)}$ - least significant difference at $P < 0.05$, NS - not significant

which imply increased soil permeability and water transmission through the soil. The K_s varies less with total porosity and more with macroporosity of the soil, (Obalum et al., 2011c), and this is particularly true for wetland soils (Obalum et al., 2011b). It could be, therefore, that the soil total porosity which differed under the four land-use options, if analysed further, would show similar values of macroporosity but not microporosity.

Influence of Land-Use Option on Some Chemical Properties of the Lowland Soils

Table 2 shows that the influence of land-use option on some chemical properties of the lowland soils. Soil pH, soil organic C, total N, CEC, Ca^{2+}, Mg^{2+}, ECEC and base saturation all showed highest values in the NUC soils and lowest values in the ABS soils. Generally, the values of these parameters differed thus NUC ≥ CCC ≥ CAU ≥ ABS. Soil pH as well as soil contents of Ca^{2+} and Mg^{2+} followed a similar trend among the four land-use options, while base saturation of the soils showed an inverse trend. This observation is noteworthy. That soil pH and the duo of Ca^{2+} and Mg^{2+} exhibited similar trends among the land-use options of *Cannabis* cultivation status sounds logical; however, these trends being opposite to that of base saturation does not.

Soil pH and base saturation are expected to positively influence each other, for they are both defined by soil contents of the exchangeable bases (Wild, 1988). On the opposing trends of soil pH and base saturation, consider that Ca^{2+} and Mg^{2+} are usually replenished in the soil via pedogenic processes, and so are not as deficient as the three primary nutrients of NPK. Also, recall that their values presented here were their determined contents in the soils, as opposed to base saturation computed using apparent CEC which is a measure of the presence of negatively charged surfaces on the soil colloids. As such, apparent CEC measures not the actual but the potential ability of the soil to exchange cations, for which it is often disproportionately higher than the ECEC, as found under NUC and CCC. From this juxtaposition, it is clear that high soil pH due to high contents of basic cations may co-occur with low base saturation where the basic cations are deficient in the soil even with elevated apparent CEC. This scenario logically explains our data showing inverse relationships between soil pH and base saturation, and the deficiency of basic cations (in this case, the pedogenically replenished Ca^{2+} and Mg^{2+}) validates the nutrient-draining effect of *Cannabis* cultivation.

A striking exception to this trend was that soil available P showed higher values in the CCC than the rest, with lowest values still in the ABS farmland. This soil available P being higher in the CCC than the NUC with a higher soil pH shows that no linear relationship existed between soil pH and

TABLE 2

Influence of land-use option on chemical properties of the soils at the lowland topographic positions in Akure area of southwestern Nigeria

Land-use option	Soil pH		SOC	TN	AvP	CEC	K^+	Ca^{2+}	Mg^{2+}	Na^+	EA	ECEC	% BS
	H_2O	KCl	(g kg^{-1})		(mg kg^{-1})	(cmol kg^{-1})							
NUC	6.6	5.8	20.2	2.0	14.32	26.70	0.25	9.10	4.35	0.16	0.83	14.65	51.90
CCC	6.0	5.1	9.3	1.8	22.38	17.43	0.37	6.80	2.95	0.18	0.78	11.22	59.08
CAU	5.3	4.5	8.2	1.4	11.54	13.60	0.38	6.33	2.37	0.25	1.46	10.89	68.60
ABS	4.8	4.0	4.8	1.6	5.83	10.78	0.22	6.06	1.88	0.18	0.85	9.20	77.36
$LSD_{(0.05)}$	0.5	0.7	3.9	0.3	7.80	6.17	NS	2.03	1.93	NS	0.12	3.68	6.45

NUC-land not used for *Cannabis* cultivation, CCC-land currently under *Cannabis* cultivation, CAU - farmlands converted from *Cannabis* to alternative use, ABS-*Cannabis* farmlands abandoned or seized; SOC–soil organic carbon, TN - total nitrogen, AvP - available phosphorus, CEC-cation exchange capacity, K^+-exchangeable potassium, Ca^{2+}-exchangeable calcium, Mg^{2+}-exchangeable magnesium, Na^+ - exchangeable sodium, EA - exchangeable acidity, ECEC - effective CEC, BS - base saturation, $LSD_{(0.05)}$ - least significant difference at $P < 0.05$, NS - not significant available P in these wetland soils, as also found by Obalum and Chibuike (2017). It is thus difficult to attribute the observation to the possibility of a linear relationship between soil pH and available P in these wetland soils. The higher content of available P in the CCC farmlands than the other land-use options in these lowland topographic positions may suggest that *Cannabis* plants (Indian hemp) can accelerate the release of available P from organic and inorganic sources under reduced soil conditions. Any such phenomenon may not be attributed to the air-drying of the soil samples done while processing them, whose effect in lowland soils of the humid tropics with appreciably high content of organic C is elevation of laboratory value of available P (Obalum and Chibuike, 2017). This is because lower values of available P were found in the NUC even with its having more than twice the soil organic C in CCC (Table 2).

Pigeon pea, an Indian crop, was also noted to increase soil available P through the release of pscidic acid which is an organic acid that promotes solubilization of P in the rhizosphere (Ae et al., 1991). Wetness of the soil microclimate for a reasonable length of time could enhance availability of soil P (Obalum et al., 2011d). Again, the limited vegetative cover that seasonally prevailed at the CCC might have minimised infiltration of rainwater and permeability and hence wetting of the soil profile up to the groundwater compared with the other three land-use options (Ouyang et al., 2019; Oguike et al., 2022). So the CCC was not expected to be the land-use option to benefit most from wetness-induced increases in soil available P. Instead, the immediate growing environment of the *Cannabis* plant must be an improved one in terms of soil water retention and management. Between *sawah*-rice and traditional rice farms in a lowland ecosystem in southern Ghana, Alarima et al. (2020) reported slight increases in soil available P over a ten-year period in the former exemplifying good water management but not in the latter exemplifying otherwise. The similar increases in soil available P due to pigeon pea elsewhere (Ae et al., 1991) and the findings in a tropical lowland ecosystem just stated (Alarima et al., 2020) put together, we infer that the higher available P under the CCC than the other land-use options in our study was both *Cannabis*- and growing environment-mediated.

All the soil fertility indices shown in Table 2 put together, however, the NUC was of higher fertility status than the CCC, CAU and ABS. These results are attributed to the afore-mentioned retention of crop residue in the NUC fields (Kolo, 2019), vis-à-vis the nutrient drain due to crop residue removal in the previous or current *Cannabis* farmlands. For cereal crops such as maize, residue retention promotes nutrient recycling (Nwite et al., 2011; Uzoh et al., 2017), as opposed to *Cannabis* where the entire plant is removed at harvest. Generally, crop residue retention leads to increases in soil organic C content with corresponding increase in total N, available P, K^+, Ca^{2+}, Mg^{2+} and micronutrient pools in the soil (Igwe, 2003; Blanco-Conqui and Lal, 2009; Smith et al., 2012; Van-Donk et al., 2012). The ABS that represents the age-long but outdated practice of fallowing in this study was expected to at least be richer than the CCC typified by non-retention of crop residue (Obalum et al., 2012b), yet its fertility status was about the lowest. The lowest values of soil pH, organic C, available P, CEC and exchangeable bases in the ABS farmland might be an indication that exhausted and abandoned *Cannabis* farmlands could deteriorate further over time. So, the degradation of lowland tropical soils due to *Cannabis* cultivation could be to the extent of the soil losing resilience, referring to its natural capability to rejuvenate after being subjected to fallow management.

No differences were observed in the contents of K^+ and Na^+ among the land-use options studied (Table 2). The exchangeable acidity (EA) showed highest values in the CAU and lowest values in the NUC soils. Notably, the CAU with the highest EA values also gave the lowest soil pH values (similar to ABS). It was possible that an inverse relationship existed between these two acidic cation-dependent soil parameters, which was expected in these hydromorphic lowland soils (Nsokpo and Ibanga, 2001; Obalum et al., 2012c).

Table 3 shows the influence of land-use option on contents of some micronutrients in the lowland soils. The content of Fe in these soils was not affected by land-use option, while the contents of Mn, Zn and Cu were higher in the NUC compared with the other three land-use options (the previous and current *Cannabis* farmlands). These results for NUC are linked to crop residue retention in the field (Igwe, 2003; Smith et al., 2012), for the associated increases in organic C often lead to improvements in soil chemical properties including micronutrients (Okoji, 1995; Saskatchewan Interactive, 2002; Tsui et al., 2004; Obalum et al., 2017).

due not only to the ongoing displacement of arable food crops by this illicit enterprise, but also to its lowering of the productivity capacity of the agricultural soils.

The data further showed generally more favourable soil physicochemical fertility indices under the CCC compared to the other two land-use options of conversion from *Cannabis* to alternative use (CAU) and *Cannabis* farmlands abandonment or seizure (ABS). This not only suggests that lowland soils degraded under *Cannabis* do not readily lend themselves to resilience, but that such land degradation progresses irreversibly even after discontinuation of *Cannabis* cultivation. The way to conserve the soil fertility in these lowlands towards maximizing their agricultural and ecological benefits is to not initiate *Cannabis* cultivation in the first place. Where *Cannabis* cultivation has already been initiated, inaccessibility to the communities indulging in this illicit practice and their farmlands due to potential security and safety threats is a major limitation to retrieving such farmlands for legitimate and profitable agricultural production. Stiffer legal and enforcement measures as well as on-site participatory scientific research initiatives would be required to tackle this problem.

However, growing of *Cannabis* showed to promote P availability under reduced soil conditions. Further study is needed in this regard to better understand the mechanisms involved. This must be in collaboration with relevant Law Enforcement Agencies

TABLE 3

Influence of land-use option on the soils' contents of some micronutrients at the lowland topographic positions in Akure area of southwestern Nigeria

Land-use option	Iron	Manganese	Zinc	Copper
	(mg kg^{-1})			
NUC	2.83	5.28	5.78	3.73
CCC	3.11	3.83	3.73	1.94
CAU	2.37	3.15	2.64	1.95
ABS	2.41	2.75	2.43	1.84
$LSD_{(0.05)}$	NS	0.96	2.01	1.16

NUC - land not used for *Cannabis* cultivation, CCC - land currently under *Cannabis* cultivation, CAU - farmlands converted from *Cannabis* to alternative use, ABS - *Cannabis* farmlands abandoned or seized, $LSD_{(0.05)}$ - least significant difference at $P < 0.05$, NS - not significant

Conclusions and Recommendations

This study of the influence of illicit practice of *Cannabis* cultivation on key physicochemical properties of lowland soils in humid tropical ecosystems has provided useful insight into the soil fertility conservation aspect of this practice. The data attained showing lower levels of soil compaction and generally higher soil fertility status under the lands not used for *Cannabis* (NUC) compared to those currently under *Cannabis* cultivation (CCC) are indications that *Cannabis* cultivation deteriorates the soil structure while the plants deplete soil nutrients reserve. It is, therefore, apt to advance the hypothesis that illicit cultivation of *Cannabis* would potentially compound the looming risk of food insecurity in highly guarded sites. The results may provide actionable framework for controlled growing of *Cannabis* not just as a means to an agronomic end – enhancing productivity of subsequent high P-feeder crops, but also for its commercial values. To this end, the required study to be led by soil/crop scientists should involve biochemical/pharmaceutical researchers to ensure that no part of such *Cannabis* plants produced with regulations is left out in harnessing these commercial values.

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