Sentinel
Social and Environmental Trade-Offs in African Agriculture

Policy Brief
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The nexus between soil degradation and agricultural expansion in Zambia

Agricultural expansion is a widespread phenomenon in Zambia and has a cyclical link to soil degradation. Soil degradation compels farmers to expand into natural habitats in search of fertile soils; however, these soon degrade into poor soils.

Summary

Crops vary in their nutrient requirements and uptake, leading to different levels of soil degradation

Continuous cropping without proper nutrient balances (export-import) degrades soil quality

The study soils have very low fertility and require a conscious adoption of integrated soil fertility management, adapted to different soil types as they vary in their resilience to degradation.

Background

This policy brief presents findings from fieldwork carried out in the Northwestern and Eastern provinces of Zambia. Soil samples were analysed from selected farms with a high land-use density to assess soil types and determine the role soil degradation plays in agricultural expansion, examining the links between farmers' wealth, the number of years of cultivation and soil fertility.

The challenge

With its soaring population, sub-Saharan Africa (SSA) boosted its food production by increasing the areas under cultivation since 1961.[1,2] This trend is set to continue as the population increases further, while land size remains the same. Agricultural expansion is an age-old phenomenon manifested in shifting cultivation systems, where over 60% and 35% of fresh farmland was obtained from undisturbed and disturbed forests, respectively.[3] Degraded soils compel farmers to encroach on uncultivated natural habitats with relatively superior soil fertility to increase crop yields. This makes soil degradation a vicious cycle in SSA agriculture, influencing agricultural expansion and land-use change, its impacts as well as trade-offs.[4] Consequently, soil degradation is a major threat to farmers' livelihoods,[5] food security,[6] and biodiversity, and a barrier to poverty alleviation. Studies show that soil factors are significant determinants of yield gaps.[7] Specifically, soil fertility alone accounts for 69% of yield gap records, whereas soil type accounts for 58%.[7] This confirms earlier findings that soil nutrients and water management, rather than improved crop varieties, are the major limiting factors in SSA agriculture.[8] For soils to provide the optimal function, there must be a balance in the integrity of their chemical, physical and biological properties, which have synergistic effects. The content and quality of soil organic matter (SOM) can curb degradation.

Soil degradation is a major challenge in cultivated soils, due in particular to nutrient mining,[9] caused by low fertilizer inputs, rapid rates of SOM depletion, and nutrient export via crop harvests.[10] This perennial scourge has resulted in widespread soil degradation, making agriculture in SSA an unsustainable venture.[10] The result is huge yield gaps, indicating an immense food security threat.[11] The Global Yield Gap Atlas suggests that the actual yields of major cereals, legumes and root crops in Zambia range between 50.5% and 51.3%.[12] This implies that yield gaps of 48.7% and 49.5% need to be closed and that the quality of soils for crop production requires more attention than it has previously been given.

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Methods

The study was conducted in the Chitokoloki - Zambezi area in the North-western province, located in the high rainfall agroecological zone and Lukweta-Katete in the Eastern province, located in the medium rainfall zone of Zambia. These locations were selected using computer-assisted multi-criteria evaluation and stakeholder recommendations. The criteria used were the presence of a land-use intensity gradient– (nearly) intact natural habitats/forests and agricultural landscapes in different ecological zones, all close to access roads. All the sites were in a size range of approximately 10 to 20 km^2, showing a contrast in terms of agro-ecological zones and natural habitats that had been lost to agriculture.

Farmers of both genders were categorised using local wealth ranking (Table 1). The major wealth indicators used were: farm size; availability of labour; type of building and roofing material used; house size; type of farm tools used; cattle herd size; and ability to pay children's school fees. Seventy-five (75) farms were selected from each location comprising twenty-five (25) farms from each wealth category and farm type (Table 1). Farms located near and around neighbouring forests or natural habitats were selected, and farms located elsewhere within the area fell into the five named categories, which were confirmed during participatory transect walks. The farm types were based on the nutrient loss trend following initial land clearing and cultivation.[10]

A quantitative method was employed with the aim to assess biological, chemical and physical soil properties to calculate soil quality indices for each farm type and wealth ranking. Soil sampling was conducted accordingly to 20 cm depth. Two categories of samples were collected for biological and physicochemical analysis. For the biological properties, soils were sampled between 40% and 80% field capacity by using a spade or shovel to scoop soil monoliths within a 25 × 25 cm square. The samples were air-dried, sieved and analysed at the School of Natural Resources Soils Laboratory, Copperbelt University, Zambia Agricultural Research Institute (ZARI), Kabwe and the Department of Soil Science, University of Ghana, in Ghana. Challenges with laboratory equipment mean that, at the time of writing this briefing, analysis of some of the physical and all of the biological properties is still ongoing. This briefing therefore focuses on interim results of the analyses conducted to date.

Results

The study found that farmers' wealth ranking had no significant effect on soil properties, although the age of the farm made a difference in some cases. About 99% of the Chitokoloki farms had soils with a sandy texture.[13] The soil map of the Republic of Zambia for 1967[14] shows that the soils are water-sorted sands called Arenosols[15] developed from alluvial and eolian materials. For Lukweta, 72% of the farms were loamy sands, whereas the remainder were sandy loams developed from acid igneous and siliceous sedimentary rocks. The texture of the soils is also reflected in the high bulk density (Table 2), but the bulk density of the Chitokoloki sands was higher than those of the Lukweta loams. The soil pH is slightly acidic (6.3–6.8) for both sites (Table 2) and fall within the range that promotes the availability of plant nutrients for most crops.[16] The delta pH (pH KCl - pH H_2O), which indicates the nature of the net charge on the soil colloids, suggests that the soils possess net positive charges and can absorb anions such as NO_3^-, PO_4^{3-}, HPO_4^{2-}, $H_2PO_4^-$, and SO_4^{2-}. This is more pronounced in the Chitokoloki soils and is reflected in the sum of exchangeable bases (Ca, Mg, K, Na), whereas it is only half of that in the Lukweta soils. The soils have very low SOM contents, as reflected in the carbon content. Seventy-five percent (75%) of the Chitokoloki farms had < 1% organic carbon (OC) (< 2% SOM) while only 47% of Lukweta farms had < 1% OC (Figure 1).

Table 1: Farm types, corresponding wealth rankings, and number of farmers sampled

Farm types	Very wealthy	Moderately wealthy	Poor	Total
a. First cultivation (cleared forest)	5	5	5	15
b. First cultivation (cleared fallow)	5	5	5	15
c. Three years' cultivation	5	5	5	15
d. Five years' cultivation	5	5	5	15
e. Ten years' cultivation	5	5	5	15
f. Grand total per location	25	25	25	75

Note: Farm ages are the upper limits (e.g. up to three years, etc.)

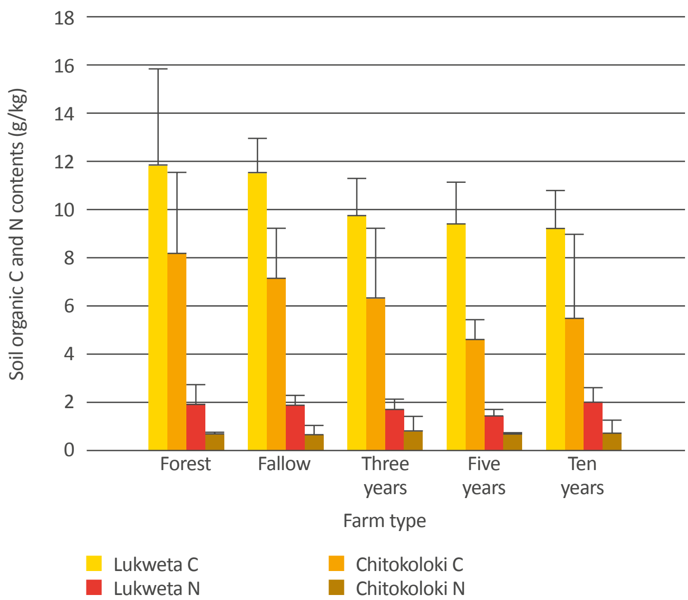
Table 2: Soil bulk density, pH and delta pH of soils from different farm types in Chitokoloki and Lukweta

Farm type	Lukweta			Chitokoloki		
	Bulk density (g/cm3)	pH water	Delta pH	Bulk density (g/cm3)	pH water	Delta pH
Freshly cultivated forest	1.4 ± 0.05	6.8 ± 0.20	1.5 ± 0.30	1.5 ± 0.07	6.4 ± 0.42	2.8 ± 0.39
Freshly cultivated fallow	1.4 ± 0.06	6.8 ± 0.26	1.3 ± 0.30	1.5 ± 0.04	6.3 ± 0.36	2.6 ± 0.38
Three years' cultivation	1.4 ± 0.08	6.7 ± 0.24	1.3 ± 0.33	1.5 ± 0.09	6.5 ± 0.37	2.1 ± 0.52
Five years' cultivation	1.3 ± 0.09	6.8 ± 0.24	1.4 ± 0.39	1.6 ± 0.06	6.5 ± 0.28	2.3 ± 0.42
Ten years' cultivation	1.3 ± 0.13	6.7 ± 0.23	1.4 ± 0.34	1.5 ± 0.04	6.5 ± 0.31	2.9 ± 0.31

Each parameter comprises a pool of five sampling points per farm in five farms per wealth category (N = 5 ± one standard deviation). The wealth rank had no effect on the soil properties so the data points are means (N = 15 ± one standard deviation)

Generally, soils with < 2% OC are subject to physical deterioration through slaking and consolidation, leading to surface sealing, etc., which are soil degradation processes.[17] Such soils are not able to develop a good structure for proper fluid conduction.

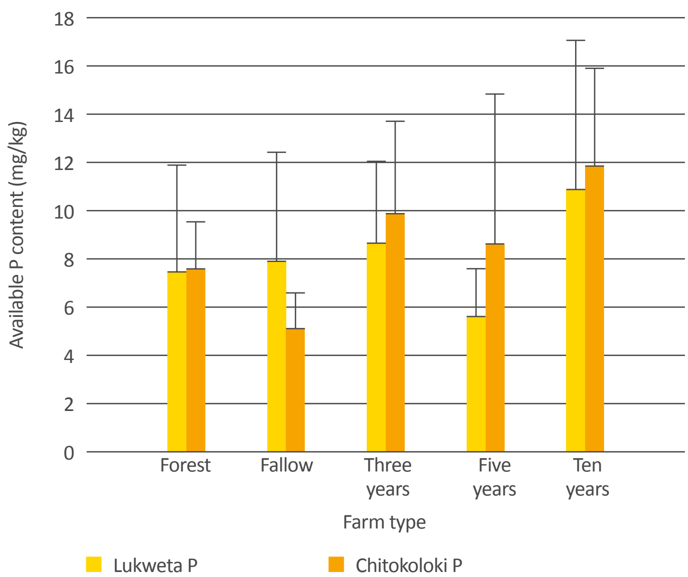
Figure 1: Soil organic carbon and nitrogen contents of soils from selected farms in Chitokoloki and Lukweta



Each bar comprises a pool of five sampling points per farm in five farms per wealth category. The wealth rank had no effect on C and N contents so the data points are means (N = 15 ± one standard deviation)

The nitrogen (N) content followed a similar trend as the OC content of both sites, except that it was relatively high considering the C-N ratio, which may be due to fertilizer application. In contrast, the Chitokoloki soils had about 6% more phosphorus (P) than the Lukweta soils. Nonetheless, the P content leaves much to be desired (Figure 2).

Figure 2: Available phosphorus content of soils from selected farms in Chitokoloki and Lukweta

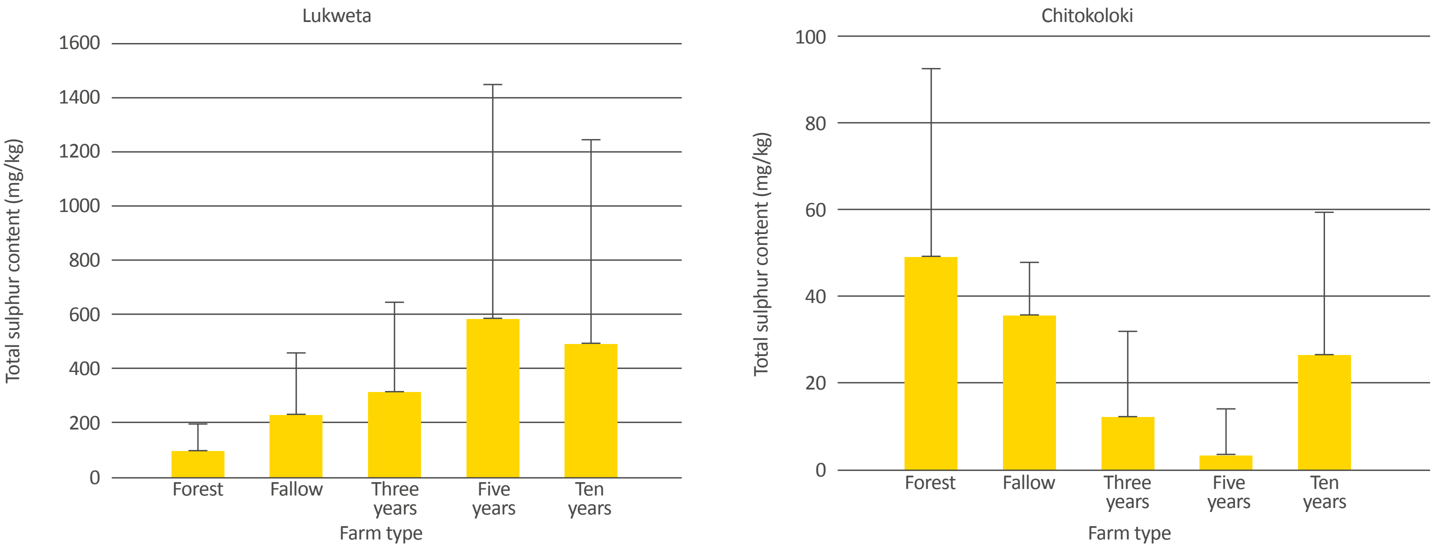


Each bar comprises a pool of five sampling points per farm in five farms per wealth category. The wealth rank had no effect on the available P content so the data points are means (N = 15 ± one standard deviation)

Only 27% of the farms from both Chitokoloki and Lukweta contained the critical available P levels of 10.9 to 21.4 mg/kg for crop yields, soil fertility and environmental safety, as suggested by Bai et al.[18] The Chitokoloki soils are said to be deficient in P because of their link with P-deficient Kalahari sandstone parent material.[19] The P content is also worsened by the low organic matter content, as there is generally low organic P pools in the soils.[19]

The mean total sulphur (S) content of Lukweta soils was 14 times higher than those of Chitokoloki – ranging from < 101 mg/kg to 588 mg/kg – whereas Chitokoloki S ranged from 12.2 to 49 mg/kg (Figure 3). In the Chitokoloki soils, S was detected in

Figure 3: Sulphur contents of soils from selected farms in Lukweta and Chitokoloki



Each bar comprises a pool of five farms per wealth category. Wealth ranking had no effect on total S content, so the data points are the means of 15 farms for newly cleared forest and fallow farms, 5 farms for three years, 1 farm for five years and 10 farms for ten years' cultivation with ± one standard deviation, because total S was not detected in some of the farms

all newly cleared forest and fallow farms, suggesting the role of SOM in S supply. For farms with less than three-, five- and ten-years' cultivation, S was detected in only 5, 1 and 10 farms, respectively. Total S was detected in all the Lukweta farms. This wide difference may be attributed to the inherently poor soils of Chitokoloki and the cropping pattern. For, instance, the Chitokoloki soils were dominantly put under pure or mixed maize (86%) and cassava cropping patterns. In Lukweta, the heavy-feeding maize only constituted 36% of the cropping patterns when nutrient-enhancing crops, such as soybean and groundnuts, were incorporated. Generally, the total S content in Zambian soils is known to be among the lowest,[20] (Tsuji et al., 2005, citing McPhilips, 1986 and Jansson, 1995) ranging between 110 and 150 mg/kg. These values were obtained from a nationwide survey of total S content on benchmark soils using geographic information.[21] The data were classified into low, medium and high S contents. Consequently, the S content of Chitokoloki soils have a low S (110-120 mg/kg), which is said to be a common trend in the area, whereas Lukweta soils have a high S content. High S deficit leads to low yields, whereas its application can boost yields and food security.[22] Over the years, soil fertility has focused only on N, P and K, as seen in the prevalence of NPK compound fertilizers. This calls for the need to include S, the fourth important plant nutrient,[22] through conscious organic and inorganic nutrient management.

The results suggest that although soil fertility is poor in both sites, the Lukweta soils are slightly more fertile than those in Chitokoloki. Furthermore, the Chitokoloki soils were dominantly put under pure or mixed maize (86%) and cassava cropping patterns that can exhaust the soil.[23,24] In Lukweta, the heavy-feeding maize only constituted 36% of the cropping patterns when nutrient-enhancing crops such as soybean and groundnuts were incorporated.

Conclusions

Based on the available data, the findings show that the soils of Chitokoloki and Lukweta are of poor fertility and are being used to grow heavy feeding crops which easily degrade vulnerable soils with low nutrient input. Soil degradation is driving agricultural expansion, by compelling farmers to seek more fertile soils, usually in natural habitats, to improve yields. However, this expansion, together with poor plant nutrient input, leads to wider soil degradation, which also affects above-ground biodiversity. There is a need to adopt integrated soil fertility management (ISFM) programmes that incorporate the recommended S rates for different crops and include intense matter management involving a crop rotation plan adapted to each soil type, given differences in their resilience to degradation.

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