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"Sedentarisation" of transhumant pastoralists results in privatization of resources and soil fertility decline in West Africa's cotton belt

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Transhumant pastoralism is an ancient natural resource management system traditionally connecting ecosystems across north-south precipitation gradients in West Africa. As rural population grew, several governments in the region have promoted their settlement, i.e., the "sedentarisation" of nomadic pastoral peoples to avoid conflict over land use and access to resources with local sedentary populations. Former transhumant pastoralists settled down and started growing crops using the manure of their livestock. This led to the dwindling of traditional agreements and exchanges (manure against crop residues) between pastoralists and agriculturalists, that resulted in less nutrients flowing between livestock, food crops and the main cash crop in the region: cotton. As a consequence, soil fertility declined, grazing areas are overexploited, and crop production is increasingly dependent on mineral fertilizers, which are produced outside the region, exposing the livelihood of local farmers to the volatility of international (oil) markets. How do local farmers perceive the effect of this virtual "privatization" of natural resources? Is the production of cotton, a main agricultural export of west African countries, a viable option in this new situation? What does this imply for the research and policy agendas to support agricultural development? We explored these questions through engaging in discussion with farmers, herders and extension agents in three cotton growing zones of Benin.

KEYWORDS

fuzzy-cognitive mapping, livelihoods, soil degradation, livestock, Sub-Saharan Africa, Benin

Introduction

In the sub-humid savannahs of West and Central Africa, traditional pastoral systems are extensive, and based on the seasonal utilization of large grazing areas by traditional, nomadic pastoral peoples (Dongmo et al., 2012). Livestock systems in the region are still relying on transhumance during variable periods of the year, following north-south rainfall patterns (Lesse et al., 2015). As population increases and grazing resources become scarce, transhumance induces low livestock productivity due to the lack of nutritional quality of fodder and its spatio-temporal variability. This drives animal movements over long distances in search for better fodder quality and water resources (Eboh et al., 2008). Crop residue biomass is essential to complement livestock diets, covering up to 80% of dietary needs during the dry season (Delgado et al., 1998; Diogo et al., 2018). Traditionally, pastoralists exchanged crop residues for animal manure by corralling their animals on agricultural fields. This resulted in important biomass

transfers (fecal excretions) over large areas, which contributed to maintain soil fertility of cropping fields. This system has been however disrupted nowadays due to population growth, conflict over natural resources, and new settlement policies in several countries of the region.

The expansion of cultivated areas has taken on considerable importance, driven by the demographic growth of indigenous populations, the arrival of migrants from other regions (including agro-pastoralists) and the promotion of cash crops, notably cotton (Ayantunde et al., 2011; Diarisso et al., 2015). Cotton production started in West Africa since the French colonial period (Bassett, 2006; Haas, 2021). Since then, cotton production increased quickly for over two decades beginning in the early 1960's (Speirs, 1991; ICAC, 2019). Cotton production plays an important role in the economy of West Africa (Soumaré et al., 2021). It represents nearly 30% of exports which contributes, in terms of value added, to 7% Gross Domestic Product (World Bank, 2016). Nowadays, Benin is the first cotton producing country in west Africa. During the last years, Benin promoted the use of external inputs such as mineral fertilizers and pesticides, which resulted in a 65% increase in production and an average 31% yield increase (DSA, 2021). This success correlated however with a generalized decline in soil fertility (Amonmide et al., 2019). As part of this process, Benin adopted a law to promote the settlement (or "sedentarisation," as it is locally known) of transhumant herders, which contemplates development projects that included granting them access to land for farming. As pastoralists became also crop farmers, they started using the manure of their animals to fertilize their own fields, while still partly maintaining animals on crop residues from other farmers during the dry season. Strong competition for organic resources emerged as a consequence of pastoralists' sedentarisation (Andrieu et al., 2015).

There is an urgency to transition toward more sustainable soil management practices in Sub-Saharan Africa, and particularly in Benin, where soils are extremely degraded (Figure 1D). How do local farmers perceive soil fertility decline and its main causes? What importance do they ascribe to the virtual "privatization" of natural resources that took place after sedentarisation? Is cotton production, the main agricultural export of West African countries, a viable option in this new situation? What does this imply for research and policy programs aiming at supporting agricultural development? We explored these questions by engaging in discussions with farmers and extension agents in three cotton-growing areas of Benin (Kandi, Pehunco and Savalou–Figures 1A, B). Participatory workshops using a semi-structured questionnaire and graphical support allowed us to collect perceptions on the causes and consequences of soil fertility decline according to each type of actor (Figure 2A). We delineated fuzzy cognitive maps together with them to describe the problem from a system perspective, and assigned weights to the relative importance they ascribed to the different factors, their causes and consequences (Figure 2C) (cf. Aravindakshan et al., 2021). Multi-dimensional scaling followed by an ascending hierarchical classification based on relative importance scores allowed for the grouping of different perceptions according to actors and zones. A total of 126 actors participated in three participatory workshops at each of the three study areas. The workshops involved 14, 12, and 17 farmers; 13, 16, and 10 herders; and 17, 16, and 11 extension agents respectively in Kandi, Pehunco, and Savalou (Figure 1C).

Context: A new configuration of rural West Africa

In the cotton-growing areas of West Africa, agriculture and livestock were typically practiced by different ethnic groups (Vall and Diallo, 2009). The adoption of livestock by other ethnic groups than the pastoralist Fulani and the mutation of pastoral systems began with the inter-ethnic peace restored during the colonial period (late 19th and early 20th century). In the 1950's, the introduction of livestock by cotton companies encouraged the first experiments in livestock rearing among traditionally crop farmers, who very quickly turned it into a secondary activity (Dongmo et al., 2012). In Benin, the practice of transhumance began with the southward migration of the Fulani people and continues to be practiced by them (Lesse et al., 2015). The farming system was characterized by the practice of fallow as a method of regenerating soil fertility. The nomadic pastoralists progressively settled down in order to, if not own land for living and agricultural activities, at least secure access to them. They have adopted cereal-based agriculture that relies on animal manure, hired labor, and herbicides, allowing them to diversify income and compensate for the decapitalization of livestock that is often experienced as a tragedy (Dongmo et al., 2012). For the past few decades, west African agriculture, and more specifically agro-pastoral systems, have been experiencing recurrent shocks that are increasingly strong and diverse under the effect of major global changes (Yapi-Gnaore et al., 2014; Diogo et al., 2021).

New cropping systems have gradually been introduced, based on mechanized tillage for land preparation and crop maintenance, mechanized sowing, use of herbicides, use of fertilizers and organic manure for soil fertility maintenance, and the application of insecticide treatments for cotton pest control (Blanchard, 2010; Yemadje et al., 2022). These new systems expanded to the detriment of traditional livestock and slash-and-burn agricultural systems, which relied on the restoration of soil fertility through fallowing (Kintché et al., 2015). Gradual "sedentarisation" of herders means that they divided their herds into two or three smaller herds that were moved to different grazing sites by different family members. Herders return each year after transhumance to their former territories, now occupied by growing numbers of cotton farmers. Herders' movement toward ecosystems that have not yet been cleared from woody vegetation alternate with transhumance movements toward territories formerly occupied by them (Sounon et al., 2019). The coercive policies on land use, privatization, and sedentarisation, plus social exclusion and marginalization led to a progressive erosion of indigenous social and economic structures. The new sedentary pastoralists were able to diversify their activity portfolio by growing crops for food and the market, capitalizing on crop-livestock interactions on their own farm (Diarisso, 2015). But this sedendarisation was also perceived as a deprivation of resources by some herders (Diogo et al., 2021), because it implied the reduction of the mobility of the herd, which formerly gave access to natural national and international grazing areas.

Farmers' perspectives on soil fertility decline

Through the different participatory workshops celebrated with crop farmers, livestock farmers and extension agents, we recorded

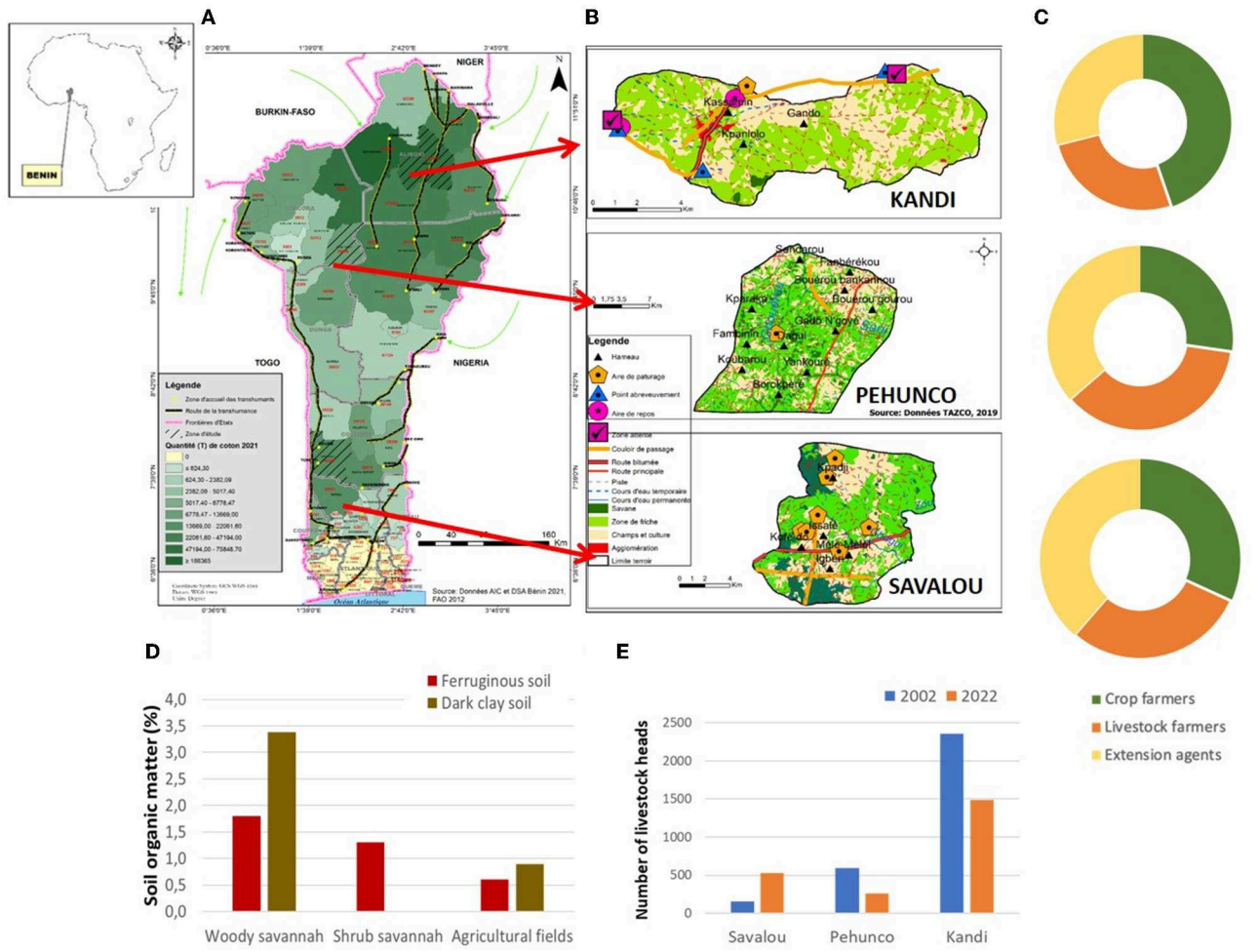

FIGURE 1
(A) Map of Benin (and Africa) indicating the cotton growing zones, main transhumance routes and location of the three study areas. **(B)** Land use maps of each study area, indicating main transhumance routes. **(C)** Proportion of crop farmers, livestock farmers and extension agents participating in this study. **(D)** Soil organic matter decline in two main soil types used from cotton cultivation, from natural vegetation to agricultural fields adapted from: Igue et al. (2013). **(E)** Number of livestock herds per study zones from 2002 to 2022 years (2022 survey).

a total of 17 drivers of soil fertility decline as identified and prioritized by these actors. Their relative importance varied for the different types of actors, and also across sites. The factors most cited by all actors, those with relative frequencies >20% and relative importance >5%, were: Tillage (frequency: 66.7%; importance: 22.9%); Monoculture (66.7%; 27.5%); Over-exploitation of land (66.7%; 17.3%); Excessive use of chemical inputs (66.7%; 36.3%), Soil erosion (33.3%; 6.7%); Burning of agricultural fields (33.3%; 6.7%); and the lack of organic matter input to soil (22.2%; 5.9%). Multi-dimensional scaling of these factors followed by a hierarchical classification based on the relative importance assigned to them allowed grouping the different perceptions according to actors and zones. This classification resulted in three classes (Figure 2B). Class 1 includes herders of Kandi and Pehunco and is characterized by the factor "Lack of organic matter input to soil" as the main factor in the decline of soil fertility. Class 2 includes farmers from the three zones, extension agents from Pehunco and Savalou, and herders from Savalou. This group identified "Tillage" as the main factor in the decline in soil fertility. The third class includes extension agents from Kandi who identified "Soil erosion" as the main factor in the decline of soil fertility. Extension agents in Kandi and Pehunco produced a more complex description of the processes leading to soil fertility decline than crop or livestock farmers did (Figure 2D).

These results indicate different perceptions of soil fertility decline between crop and livestock farmers. While the former identified lack of organic matter inputs to soil (due to removal of crop residues, no or insufficient manure applications) as the main cause of soil fertility decline, livestock farmers identified soil tillage as the main factor. We did not observe any difference in perception between the different zones, which indicates that the problem is similar in the cotton zones of Benin. However, as indicated by the fuzzy cognitive maps (Figure 2D), the description of the process of soil fertility decline by all actors tended to be more complex in Kandi, where conflict over land is more acute. The decline in soil fertility has led to an increase in cultivated areas, a drastic decrease in the size of individual livestock herds (Figure 1E) due to difficulties in accessing feed. Sedentarisation led to the disappearance of farms that specialize in a single agricultural activity and the emergence of mixed farms. Nowadays, livestock farmers increasingly produce crops and crop farmers keep livestock, exerting greater pressure on the natural

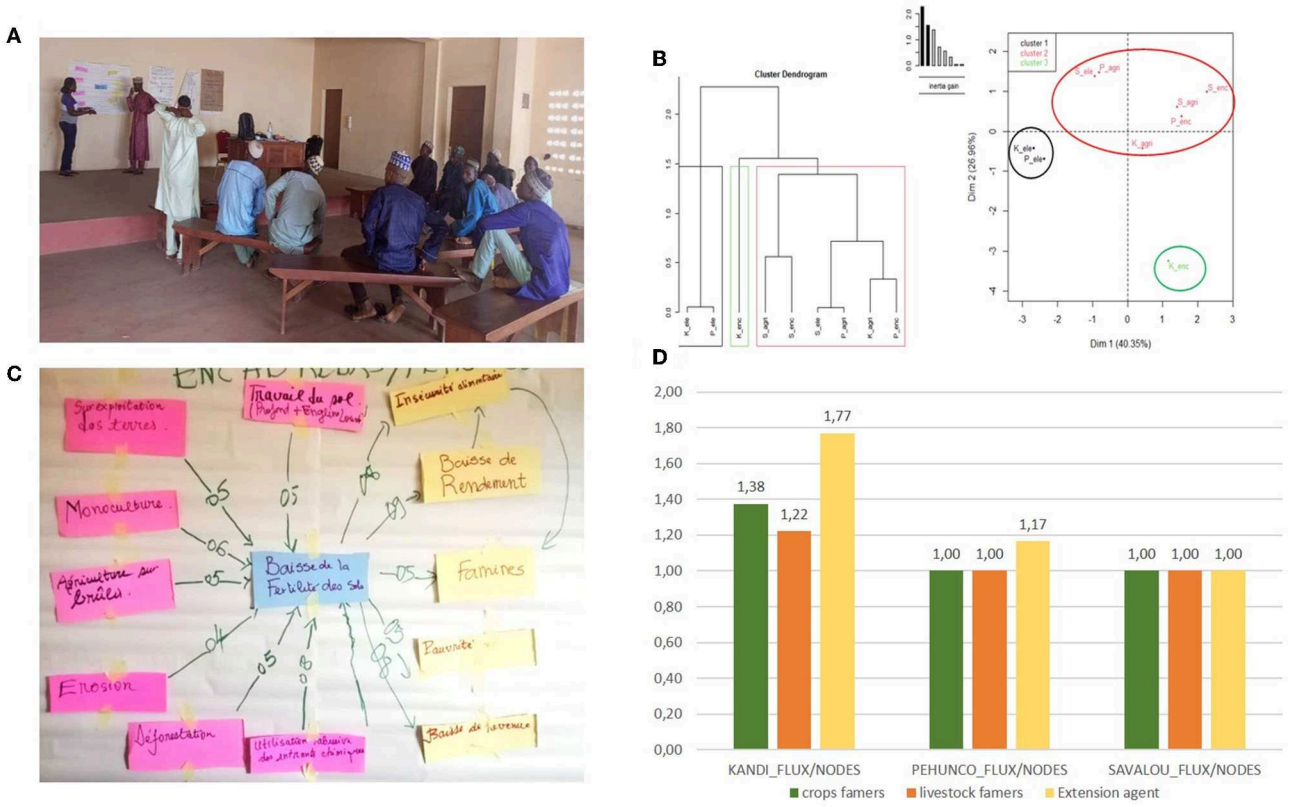

FIGURE 2
(A) Picture taken during the participatory workshops with farmers; **(B)** Picture of a fuzzy-cognitive map representing farmers' perceptions on the processes that lead to soil fertility decline (number on each arrow indicates the relative importance of each driver); **(C)** Hierarchical bottom-up classification of producers and supervisors in the different zones according to their perceptions of soil fertility decline factors; **(D)** Degree of complexity of the perception of the different actors as measured by the ratio of interactions per concept (flows to nodes, or arrows to boxes ratio).

resource base. Although none of the three types of participating actors pointed to pastoralists' sedentarisation as a main cause for soil fertility decline, the growing preponderance of mixed farms leads to high competition for manure, grazing areas and feed resources, which leads to less organic matter inputs to soil.

Discussion

The experience of farmers and their knowledge of the environment represent benchmarks for assessing soil fertility (Kambiré et al., 2022). Our study reveals a decrease in the size of cattle herds per individual due to the scarcity of fodder quality and quantity, the disappearance of specialized farms, a concentration of fertility on former pastoralists fields due to the mobility of their animals, and soil management factors as the main causes of soil fertility decline according to farmers, herders and extension agents. Favoring participatory approaches that integrate farmers' opinions in the assessment of alternatives to soil fertility management is a widely shared approach in the research and development community today.

Tittonell and Giller (2013) compiled ample evidence on drivers of soil fertility decline in Sub-Saharan Africa, as the main threat to the food and nutritional security of smallholder farmers. As reported by these authors, farmers in our study zones have strongly linked soil fertility decline with frequent tillage and the lack of organic matter input to soils. Tillage changes soil structure, its porosity and the distribution of fresh organic matter restored or supplied (Bouthier et al., 2014). Also, tillage exposes soil to oxidation, increasing greenhouse gas emissions and loss of organic matter (Smith et al., 2011; Lognoul et al., 2017), and in Ferruginous soils it may lead to soil degradation through compaction and erosion, affecting water availability and long term crop yields (Smith et al., 2011; Lognoul et al., 2017; Yemadje et al., 2022). Failure to return organic matter to soil decreases soil fertility (Warren et al., 2015). Organic matter inputs to soil can be achieved by parking animals on the crop fields after collecting the crop residues, or through storing the residues *in-situ* by keeping the livestock away. But in the West African context, due to the development of animal traction and the diversification of farms, crop residues are increasingly used to feed livestock. For example, up to 90% of farmers' crop residues may be consumed by the livestock of (agro) pastoralists (Diarisso et al., 2015). Compensating for this removal by the return of animal dung is a trade-off that is struggling to take off because the manure available in the village is mainly used to fertilize the pastoralists' fields. As a result, the croplands of farmers with few livestock are continuously tapped for nutrients (Baudron et al., 2015; Diarisso, 2015).

Livestock-mediated transfers of organic matter and nutrients from non-cultivated to cultivated areas has been historically one of the main determinants of soil fertility maintenance in semi-arid and sub-humid regions of West Africa, at least for farms with large

numbers of cattle (Harris, 2002; Achard and Banoin, 2003; Schlecht et al., 2004; Diarisso et al., 2015). The sedentarisation process initiated by herders as an adaptation to global change, and legalized by policies, allowed peaceful agreements between crop and livestock farmers, which prevented long standing conflicts; but it does not necessarily guaranty the sustainable use of resources. By increasing the number of mixed crop-livestock farms in a territory, sedentarisation of herders led to strong competition for grazing and feeding resources, and to a shortage of animal manure to fertilize an ever expanding agricultural area.

Such a result may be counterintuitive, as crop-livestock integration on farm is often proposed as a sustainable pathway for agricultural intensification (e.g., Tittonell et al., 2015; Martin et al., 2016; Paul et al., 2020). Manure contracts made by farmers with foreign pastoralists on transhumance are no longer possible, while sedentary livestock keepers carrying out a mixed activity on their farms will not necessarily be open to a manure contract. When a livestock keeper engages in crop production, the substitution rate between livestock and crops is low, that is, the cropping area increases without a concomitant proportional decline in livestock. This is because crop production is more intensive than livestock production, which relies mainly on natural grazing (Ayantunde et al., 2011). The result is higher pressure on the natural resource base at community level.

Cotton, being a locomotive for the rural economy of West Africa, is not spared from the impacts of these changes and is cited by some authors as the cause of soil degradation due to its rapid expansion and nutrient requirements (Njomaha, 2003; Da et al., 2019). However, mineral fertilization of cotton has significant effects on the yields of subsequent food crops in the rotation, due to the residual effects of fertilizers, particularly on savanna soils that have been exploited and have low levels of organic matter (Ripoche et al., 2015). Fertilizers are provided by the cotton industry on credit, and these are often the only nutrient input to these farming systems annually. Several alternative sustainable management techniques have been tested in Sub-Saharan Africa to improve soil fertility, yields and enhance soil organic matter (Vanlauwe et al., 2010; Chivenge et al., 2022; Thierfelder and Mhlanga, 2022; Yemadje et al., 2022), yet their adoption by farmers remains limited. This situation calls for researchers and policy makers to find a solution that allows both agriculture and livestock to coexist in a sustainable manner. In the current socio-political context of West Africa, a return to cross-border transhumance may be more inconvenient than sedentarisation.

Avoiding a new tragedy of the commons

By threatening cotton cultivation, sedentarisation and the consequent unorganized expansion of mixed crop-livestock farms may have thus both direct and indirect negative impacts on local food security. In such a challenging climatic, socioeconomic and institutional context (uncertain and changing), cropping and livestock systems must be transformed to adapt and ensure their viability. Sedentarisation policies evolved as a response to conflict but without a parallel redesign of the agroecosystems, which resulted in a "tragedy of the commons" in terms of organic matter resources. Research and policy must find new compromises between sedentary pastoralism and agriculture, as livestock and crop production cannot be disconnected or conducted individually.

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

GD collected, analyzed, and edited the data. PT and PY supervised the research, contributed to the design and structure of the article, and co-edited the manuscript. RD and OB participated in improving the manuscript. All authors contributed to this article and approved the submitted version.

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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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