ENVIRONMENT

DOCTORAL THESIS

ORGANIC MATTER DYNAMICS IN MIXED-FARMING SYSTEMS OF THE WEST AFRICAN SAVANNA

A VILLAGE CASE STUDY FROM SOUTH SENEGAL

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Organic matter dynamics in mixed-farming systems of the West African savanna: a village case study from south Senegal

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RESUME

La matière organique (MO) remplit de multiples fonctions dans les systèmes agro-pastoraux de savane d'Afrique de l'Ouest. Elle fournit de l'énergie, des éléments minéraux et des matériaux de construction aux paysans et aux animaux. Grâce à la jachère et à la fumure animale, elle assure l'entretien du système par des mécanismes biologiques. Dans la région, la disponibilité en MO peut être utilisée comme un indicateur de durabilité des systèmes de production traditionnels, car malgré une population croissante, les rendements progressent peu en raison d'un faible accès aux intrants chimiques. Les bilans du carbone (C), de l'azote (N) et du phosphore (P ; total dans la plante, assimilable dans le sol et noté P_{OD}) ont donc été établis pour un terroir agro-pastoral dans le sud du Sénégal afin d'en estimer la viabilité à différentes échelles, de la parcelle au village.

Le terroir choisi était organisé en auréoles, avec une intensification croissante des pratiques de la périphérie vers le village. Trois grandes unités de gestion des terres ont pu être mises en évidence : (1) l'auréole des champs de brousse, soumise à l'agriculture itinérante, (2) l'auréole des champs de case, en culture continue grâce à la fumure organique, (3) un bas fond rizicole périodiquement inondé. Les sols étaient sableux ferrugineux (Lixisols), sauf en bas fond (Gleysols). La densité de population humaine était de 33 habitants km^{-2}, celle de bovins de 51 unités de bétail tropical km^{-2}.

Une approche parcellaire a montré que les stocks dans le système sol-plante (jusqu'à 40 cm de profondeur) étaient de 27,8 tC, 2,03 tN et 17,3 kgP ha^{-1} dans les champs de brousse en arachide et s'élevaient à 54,7 tC, 2,63 tN et 43,5 kgP ha^{-1} dans les jachères âgées de plus de 10 ans, la majorité de l'augmentation ayant lieu dans la biomasse végétale. Dans le sol, la croissance rapide des stocks durant la première année de jachère (20 %) fut suivie par une stagnation (C, N) voire une régression (P). Dans six parcelles de céréales de case, les stocks mesurés étaient supérieurs à ceux des parcelles de cultures de brousse et s'élevaient à 29,9 tC, 2,30 tN et 83 kgP ha^{-1}. L'augmentation des stocks de P_{OD} fut significative à toutes les profondeurs et dans toutes les parcelles. Ce ne fut pas le cas pour le carbone et l'azote, dont la teneur ne s'améliora significativement que dans l'horizon 0-10 cm, et principalement dans les parcelles jouxtant les concessions et recevant les apports de MO minéralement les plus riches. Les stocks de C, N et P les plus élevés furent mesurés dans les rizières, aux sols à texture fine.

Le modèle conceptuel suivant a été proposé pour interpréter la faible réponse des stocks de carbone des sols sableux à la jachère et à la fumure, en réévaluant le rôle biologique et thermodynamique joué par le carbone grâce à son recyclage. Dans les sols tropicaux sableux de la zone, la biosphère contrôle fortement les propriétés physiques du sol et la disponibilité en éléments minéraux de la plante. Les systèmes racinaires pérennes, ou les apports de fumure organique exogène, sont nécessaires pour maintenir l'intégrité fonctionnelle de l'écosystème sol, car ils fournissent au biote l'énergie et les éléments minéraux nécessaires à son entretien.

Par intégration d'échelle, les stocks moyens contrôlables par la gestion des terres par l'homme furent estimés à 29,7 tC, 1,52 tN et 28,6 kgP ha^{-1} (horizon 0-20 cm considéré pour le stock du sol) en 1997. Le carbone était stocké principalement dans le sol (50 %), la biomasse aérienne ligneuse (22 %) et les souches (8 %). Les récoltes, l'élevage et la collecte de bois ont représenté respectivement 27, 59 et 14 % des prélèvements de carbone dans l'espace approprié par le village. Les animaux ont assuré 79 à 85 % des retours de C, N et P aux parcelles. Par ce système de flux, des quantités importantes de carbone ont été apportées aux champs de case (3,8 tC ha^{-1} an^{-1}), et les pertes d'azote et de phosphore du système furent estimées à seulement 4 kgN et 1 kgP ha^{-1} an^{-1}, ce qui indique que le terroir est proche de l'équilibre minéral.

Dans les conditions actuelles de croissance démographique, la perte de carbone pourrait cependant atteindre 0.38 tC ha^{-1} an^{-1} durant les trois prochaines décennies, tandis que les flux de carbone liés à l'élevage et aux récoltes doubleraient dans le même temps. La viabilité du système pourrait donc être remise en question durant les prochaines années, si aucune intensification des pratiques n'a lieu.

MOTS CLES

Azote, Biomasse, Carbone, Elevage, Fertilité, Flux, Fumier, Jachère, Matière organique, Phosphore, Plante, Sénégal, Sol, Stock, Terroir agro-pastoral

ABSTRACT

Organic matter (OM) is a multi-purpose tool in smallholder mixed-farming systems of West African savannas (WAS). It provides people and animals with energy, nutrients and construction materials. Its cycling also ensures the biological maintenance of the system, mainly through fallowing and manuring. In the WAS, population grows faster than yields of food crops. Since access to industrial inputs will remain low in the coming years, OM availability can be used as an indicator of sustainability of local farming systems. Carbon (C), nitrogen (N) and phosphorus (P; total in plant, available in soil and noted P_{OD}) budgets were thus quantified in a tropical mixed-farming system of southern Senegal to assess its viability from the plot to the village levels.

The village territory of the study showed a ring-like, compound-centred organisation. Growing intensification of fertilization and cropping practices, from the periphery to the compounds, led to the distinction of (1) a plateau bush ring under semi-permanent cultivation (2) a compound ring under continuous cultivation receiving manure from night corralling and household wastes (3) lowland, seasonally flooded, rice fields. Soils were sandy Lixisols, except in the lowland (Gleysols). Human and livestock densities were respectively 33 inhabitants and 51 tropical livestock units km^{-2}.

According to the plot study set at the beginning of the rainy season, stocks in plant and soil (down to 40 cm deep) increased from 27.8 tC, 2.03 tN and 17.3 kgP ha^{-1} in groundnut crops of the bush ring to 54.7 tC, 2.63 tN and 43.5 kgP ha^{-1} in fallows aged more than 10 years. Plant biomass accounted for nearly all of the rise. In soil, fast increase within the very first year (+20 %) was followed by stagnation (C, N) or even decrease (P_{OD}) of stocks. In six more or less manured cereal fields of the compound ring, stocks were 29.9 tC, 2.30 tN and 83 kgP ha^{-1}. Large increase of soil P_{OD} stocks in comparison to cropped bush fields was recorded at all depths and in all plots. Although significant, increases of soil C and N stocks were restricted to the 0-10 cm layer, and occurred mainly in fields adjoining farmyards, which received organic inputs with highest chemical inputs. Highest C, N and P amounts were found in lowland rice fields as a result of soil fine texture. To account for the weak response of local sandy soils to management, a plant-soil conceptual model, reassessing the thermodynamical signification of soil organic carbon cycling was proposed. In these tropical sandy soils, biota strongly controls soil physical properties and nutrient availability to plant. Perennial rooting systems, or manure exogenous inputs, are thus needed to sustain the ecosystem structural and functional integrity, since they fuel the soil biota with C-mediated energy and nutrients.

Integrative estimates for manageable stocks of the whole village territory were 29.7 tC, 1.52 tN and 28.6 kgP ha^{-1} (soil stocks: 0-20 cm layer considered only) in 1997. Main C pools were soil (52 %), woody above-ground biomass (22 %) and stumps (8 %). Crop harvest, livestock, and wood and straw collecting were responsible for respectively 27, 59 and 14 % of the C outflows from the area exploited by the village. Livestock accounted for 79-85 % of the C, N and P returns to the soil. As result of these transfers large C

inputs were brought to the compound ring (3.8 tC ha^{-1} y^{-1}). N and P depletion of the system amounted to 4 kgN and 1 kgP ha^{-1} y^{-1}, suggesting that the system was close to nutrient balance.

Under current demographic growth rate, simulated C depletion of the village farming system may reach 0.38 tC ha^{-1} y^{-1} during the next three decades; meanwhile C flows related to livestock activity and crop and wood harvest should double. The viability of the system might thus be called into question within the next few years, if practices of cropping and animal husbandry are not intensified.

KEY WORDS

Biomass, Carbon, Fallow, Fertility, Flux, Livestock, Manure, Mixed-farming system, Nitrogen, Organic matter, Phosphorus, Plant, Senegal, Soil, Stock

To my parents

To the people of Sare Yorobana

FOREWORD

This work was initiated in the framework of the European Union Projects "*Reduction of the Fallow Length, Biodiversity and Sustainable Development in Central and West Africa*" (TS3-CT93-0220, DG12 HSMU) and "*Improvement and management of the fallow lands in West Africa*" (Project n° 7 ACP RPR 269, DG8). These projects have been conducted since 1994 in Burkina Faso, Cameroon, Ivory Coast, Mali, Niger and Senegal. In Senegal, these programs have acted as a research and development network; they have focused mainly on the understanding of the functioning of fallow ecosystems and alternative farming systems (research activities) and on the briefing of techniques that can be passed on due to contracts with rural organisations (development actions). In this country, the network implied both local partners such as the Senegalese Institute for Agricultural Research (ISRA) and foreign institutions like the French Institute for Research and Development (IRD, ex-ORSTOM, initiator of the project), and the French International Centre for Agricultural Research in Hot Regions (CIRAD).

The fieldwork reported in this thesis was conducted in Sare Yorobana, the wettest of the two main study sites chosen by the IRD team for its field experiment in Senegal. Both diachronic and synchronic studies were -and still are- held in these sites. Synchronic measures were aimed at characterising the dynamics of natural fallow (chronosequences) and some of the work is reported here. Diachronic experiments were set to evaluate the impact of the introduction or elimination of ecologically functional key-groups (tree, soil macrofauna, perennial grasses, woody nitrogen fixing species) on indicators of soil chemical, physical and biological properties, biodiversity and plant productivity (1994-1998), as well as their effect on crop after the clearing of fallow (1998-2001).

In Senegal and in France, the Program for the "*Improvement of Feeding Systems of Tropical Livestock*" ("*Alimentation du Bétail Tropical*") (held by the Department of Animal Production and Veterinary Medicine (EMVT) of CIRAD brought strong scientific support to this work too. This Program is involved in the study of current practices of extensive herding of small ruminants and livestock in West Africa, as well as in the adoption of new practices to improve animals' health and productivity and their owners' incomes. In Senegal, this Program initiated the scientific studies in the village of Sare Yorobana in the mid-80s and provided all data dealing with livestock-mediated transfers used in this thesis (Chapters 4 and 5).

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The French Institute of Forestry, Agricultural and Environmental Engineering (ENGREF) is "*an application school of the Ecole Polytechnique and the Institut National Agronomique Paris-Grignon in its initial vocation, responsible for the training of the Corps of [civil servants] engineers of rural engineering, water, and forests (GREF); the school has now broadened its training, alone or in partnership (master's and doctoral level training). (…) ENGREF is authorised to grant doctorates in the fields of its competency and the school develops scientific collaboration with numerous outside partners*" (ENGREF, 2000). The Corps of the GREF gives the opportunity to a tenth of its students to undertake a PhD thesis. The student is put on secondment in a laboratory of ENGREF or of another research institute (here IRD), by the French Ministry for Agriculture and Fishery, which thus funded a part of the research work reported here.

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