N° d'ordre : 10
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UNIVERSITE D'ABOMEY-CALAVI
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ECOLE DOCTORALE DES SCIENCES DE LA VIE
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THESE

Présentée

POUR L'OBTENTION DU DIPLÔME DE
DOCTORAT UNIQUE EN SCIENCES DE LA VIE

Dominante : Sciences Biologiques **Sous Dominante : Sciences Sociales**

OPTION : Agronomie : Fertilité et fertilisation des sols

PRESENTEE PAR

Aliou SAIDOU

Thème : Analyse de l'efficacité agronomique et de la rationalité des pratiques paysannes de gestion de la fertilité des sols au Bénin

Soutenue le 19 Octobre 2006, devant le jury d'examen :

Rudi RABBINGE	Professeur à l'Université de Wageningen	Président
Dansou KOSSOU	Maître de Conférences Université d'Abomey-Calavi	Directeur de Thèse
Brice A. SINSIN	Professeur à l'Université d'Abomey-Calavi	Rapporteur
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Paul RICHARDS	Professeur à l'Université de Wageningen	Examinateur
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Thème : Converging Strategies by Farmers and Scientists to Improve Soil Fertility and Enhance Crop Production in Benin

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Abstract

Farmers in the transitional zone of Benin claim that extensive cassava cropping and prior cotton fertiliser enhance yield of subsequent maize. To cope with labour shortage, farmers have adapted fertiliser practices by mixing NPK-SB and urea. We agreed with farmers through a Stakeholder Learning Group to study these innovations. In this process land tenure arrangement was also of interest because it affects long-term soil fertility management. Joint experiments opened a path between farmers' interpretations and scientific explanations of earthworm activities. The presence of earthworm casts is used by farmers as an indicator for soil health. Farmers understand casts to be a kind of 'vitamin' indicating good conditions for crop growth. Cassava cultivars did not significantly change soil chemical properties. However, cassava cultivar, subsequent fertiliser treatment, and farmers' management significantly affected maize grain yield. The nutrient uptake ratios indicated that P was the main limiting nutrient. Results from a subsequent pot experiment provided evidence that arbuscular mycorrhizal associations may be part of the explanation for the farmers' claim of beneficial effects of cassava. Farmers were knowledgeable about residual effects of fertiliser. Cotton yield, soil chemical properties, subsequent maize yield and nutrient uptake were significantly affected by land use types. The N : P ratios of nutrients taken up indicated that P was relatively more limiting in the egusi-cotton-cotton system, whereas N was relatively more limiting in the cassava-maize-cotton system. This result is consistent with the hypothesis that cassava improves P nutrition of a subsequent crop through mycorrhizal carry-over effects. Co-research activities apparently improved both human capital (farmers' individual knowledge and capacity building) and social capital (group dynamic, space for innovation, interaction, negotiation skills, improvement of cropping practice, improvement of social relationships, and information sharing). Farmers' knowledge on the role of N, P and K nutrients and arbuscular mycorrhizal fungi had been highly improved. With regards to land tenure, the problem to be overcome is how to change mutual perceptions of tree planting as a covert claim to land ownership, since agroforestry is a potential key to soil fertility maintenance. Formal written-down land use rules, including adoption of agroforestry with *Gliricidia sepium* for permanent yam production and improved soil management practices were negotiated. This document approved by both land owners and migrant farmers does not alter the existing balance of power.

Keywords: Farmer perception, indigenous knowledge, extensive cassava, earthworm casts, arbuscular mycorrhiza, crop rotation, nutrient uptake, soil fertility, co-research, land tenure.

Dedicated to my late father Alassane Saïdou, my late grandmother Aminintou Bello, my mother N'zué Kouassi, my wife Mariam, my children and all the farmers of Savè and Atacora-Donga regions.

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Aliou Saïdou
Cotonou, 28 August 2006

Contents

Chapter 1

General introduction

A. Saïdou

General introduction

Soil fertility management is an integral part of cropping systems management with its particular spatial and temporal characteristics. Scoones and Toulmin (1998) mentioned that soil fertility is a dynamic concept, where degradation and build-up of soil can simultaneously occur at different scales over space and time. There are basically two ways to look into soil fertility management; *i.e.,* through the hard and soft science approaches (Engel and Salomon, 1997). The 'hard' science approach uses and generates fundamental or technical knowledge on soil fertility management; whereas the 'soft' science approach uses a combination of experiential and religious-cultural knowledges (Deugd *et al*., 1998; de Jager *et al.,* 1999). Somehow, these two approaches are underpinned by different views on the nature of technology and the difference between what is technologically feasible and socially acceptable. For example, when researching soil fertility management technology we need to observe not just only the technical aspect but also farmers' organisation (labour management, market opportunity, land tenure, etc.) and practices (especially crop management). However, proper understanding of the social organisation requires an analysis of how various actors organise themselves to confront problems of land degradation and subsequent crop yield decrease.

Land degradation and poverty

Land degradation and unsustainable use of natural resources are limiting the potential for agricultural development in sub-Saharan Africa. Land degradation can take a number of forms, including nutrient depletion, soil erosion, salinisation, agrochemical pollution, degradation of vegetation from overgrazing and the cutting of forests for farmlands (Scherr and Yadev, 2001). All these forms of degradation cause a decline in the productive capacity of the land, reducing attainable and potential yields. A constant theme in diagnoses of the causes of rural poverty in sub-Saharan Africa is the potential or predicted failure of the rural resource base (land, water, forests, or pasture) to sustain rural people's livelihoods (Woodhouse, 2003). However, the InterAcademy Council (IAC) (2004) reported that West Africa has actually managed to increase agricultural production, even if this has been to some extent to the detriment of soil fertility restoration, because smallholder farmers tend to practise low external input agriculture. The IAC report shows that tuber crop (*e.g.*, cassava, yam, etc.) yields have grown modestly in farming systems in which they are the principal commodities. However, cereal crop yields (maize, millet, sorghum, etc.) have grown significantly in the irrigated and commercial farming systems.

The continued threat to African land resources is exacerbated by the need to reduce poverty (Sanchez *et al.*, 1997; Sanchez, 2002). Smallholder farmers in Africa deploy their own logics when managing their land. Their attitude to soil and land management is part of their livelihood improvement strategies. An example is the trade-off between short term solutions (reducing the fallow period) and long term solutions (increasing soil productivity) as documented by Samaké (2003) in Mali. In fact, this author mentions an increase of production during the past decades obtained mainly by increasing land area under cultivation and decreasing fallow periods. Indeed, a year with fallow has yield nil, so knocking out a fallow year in favour of continuous cropping raises aggregate output over the short term only to induce a decline in the longer term. Removing fallows without corresponding change in soil management is certainly not sustainable in the long term. Reversal of soil fertility depletion, and intensification (if fertilisers are available) and diversification of land use with high-value products, are some of the requirements identified by Sanchez and Leakey (1997) for increasing per capita agricultural production. Nevertheless, in developing countries these high-value products are often more for the market than for farmers' consumption.

Based on nutrient balance studies (Smaling, 1998; Bindraban *et al.*, 2000; Smaling *et al.*, 2002; Koning and Smaling, 2005) and on field observations across Africa (Sanchez *et al.*, 1997; Sanchez and Jama, 2002), it is concluded that soil fertility depletion in smallholder farms is now increasingly recognised as the key bio-physical constraint for crop production in Africa. Smallholder farmers removed large quantities of nutrients from their soils without applying sufficient quantities of manure or fertiliser to replenish the soil. Low fertility, however, does not stand on its own. It belongs to a complex of constraints. If low inherent fertility is the intrinsic African bio-physical constraint, then tenure insecurity is a major social constraint, insecurity of farm labour due to better opportunities in towns for young migrants and lack of markets two major economic constraints, price of fertiliser a financial constraint, and dumping of agricultural produce by the European Union and United States of America a major political constraint. Soil fertility is an important part of the problem, but cannot be solved on its own. Doumbia and Sidibé (1999) cited by Kanté (2001:1) are probably correct to state that "*when a soil is poor, people cultivating it are also poor*", but that quote should not be read as a statement about cause and consequence. Poverty, due to socio-economic constraints, may be an important cause of the inability of farmers to maintain soil fertility. This is why this thesis looks for an interdisciplinary approach to solutions addressing soil fertility management and issues of institutions (specifically land tenancy).

In Benin, nutrient depletion due to high population density, resulting in the breakdown of the traditional land use system through shortening of the fallow period (Houndékon and Gogan, 1996; Saïdou *et al.*, 2003) is one of the main causes of the decline of soil productivity (Brouwers, 1993; Bernard, 1995; Gaiser *et al.*, 1997). Shortening fallow and the transition towards permanent cropping systems require a change in the cropping system (Sauerborn *et al.*, 2000). The breakdown of the traditional system should also be understood in terms of social factors, including labour availability. As an example, Vissoh *et al.* (2006) have shown that in southern Benin labour turned out to be much more important for weeds than poor soil fertility per se. Many farming decisions are driven by the need to optimise allocation of labour (Olatoundé, 2005).

One of the reasons behind the seeming inability to stop nutrient depletion is the low priority given to the rural sector by policy makers (Sanchez *et al.*, 1997). Subsidies on fertiliser purchase and distribution have been abandoned as a consequence of the structural adjustment programs, and the private sector has been encouraged to take over supply systems. But a clear consequence of state disengagement is the decrease in the amount of fertiliser used, given its high price (Scoones and Toulmin, 1998). The low national priority given to the rural sector in Africa results in lack of timely access to credit and input, lack of timely information, and ineffective extension systems (Badiane and Delgado, 1995; Tomich *et al.*, 1995; Sanchez and Jama, 2002). Even where the private sector supplies the necessary inputs farmers lack access to credit to buy it. Higher priority needs to be given to rural infrastructure, to policy research and policy dialogue (Sanchez and Jama, 2002) as recommended by the Soil Fertility Initiative (SFI) (FAO, 1999).

The SFI for sub-Saharan Africa was launched under World Bank leadership. The World Bank assumes that soil regeneration in Africa should be undertaken as a public investment. Therefore, in addition to technological aspects, SFI will need to address policy issues in order to ensure that farmers derive profits from the measures which they will be encouraged to adopt. Some argue, however, that effectiveness is doubtful, as it remains unclear who exactly will pay the bill (Keeley and Scoones, 2000). In their analysis, these authors highlighted the lobbying aspects of scientific research, bureaucratic ambitions of international organisations, and the role of the fertiliser industry. In the context of the SFI program in Benin, workshops have been organised at each department level and at national level. A project document has been written (MAEP, 2002) but the government is still looking for funding. This national soil fertility management program emphasises science-based research and extension activities with special attention to agroforestry, compost, mineral fertiliser and cover crops, as technologies to improve crop yields. The approach ignores farmer indigenous knowledge. The soft side of the land (tenure, labour, market opportunities, etc.) are also ignored. Consequently, the SFI program runs a risk that it will provide resources only to the scientists and extension services, to the detriment of farmers supposed to benefit from the project.

Relevance of local innovation

Local innovation is the process through which individuals or groups discover or develop new and better ways of managing resources, building on and expanding the boundaries of their indigenous knowledge (Waters-Bayer and van Veldhuizen, 2005). Promoting local innovation is to move beyond the existing innovations farmers have developed, using their indigenous knowledge and creativity, and to develop these ideas further in joint experimentation. In the past, rural development efforts usually focused on technical interventions relying on the use of external inputs, while West African agriculture was organic by default, not because farmers disliked fertiliser and similar inputs (Ayenor *et al*., 2004) but because of financial constraints and lack of availability of external inputs. These efforts generally failed to improve the farming and livelihood systems of the poor. A good example is velvet bean (*Mucuna* sp.) (Douthwaite *et al*., 2002). Farmers complain that one cannot eat and not even sell the beans, that it is hard and painful to incorporate the vegetative matter into the soil, and that the bean occupies the land for the whole cropping season during which time food production is impossible. Another example is the use of compost to improve soil organic matter content. Farmers complain that it is hard and painful to transport the compost to the field, and that the raw materials (cow dung, crop residues, etc.) to produce sufficient quantities of compost are often not available for the whole year.

Studies on indigenous knowledge (Richards, 1985; Pawluk *et al*., 1992; Reij *et al*., 1996; Sillitoe, 1998; Prain *et al*., 1999; Warkentin, 1999; Waters-Bayer and van Veldhuizen, 2005) emphasised that land-users often have extensive knowledge of the local environment. Despite the fact that these land management practices fit local cropping systems, they are not always appropriate, because farmers still complain of soil fertility decline and of crop yield decrease.

Resource management and land tenure

Over time, the vital role that land plays in sustaining life for human beings has led societies to establish arrangements concerning the ownership and use of land, usually referred to as land tenure. Tenure is an institution with its own dynamics defining the relationships between individuals and their rights and obligations with respect to control and use of land (Manyong and Houndékon, 2000; ECA/SDD, 2004). Matlon (1994) defined land tenure as the rules and procedures governing the rights, duties, liberties, and exposure of individuals and groups in the use of and control over land and water. Land tenure is one of the central factors determining food security and sustainable development. Unequal access to land and insecure land tenure have a profound effect on the livelihoods of smallholder farmers in Africa.

African customary tenurial systems are often characterised by the inalienability of land. Note that the concept of 'customary' rights sometimes empowers certain groups and deprives other groups access to land, or grants access only on very inadequate terms. In the case of migrants in Benin, the customary now functions as an exclusion mechanism, even though this seems not to have been the case in former times (many communities among the Yoruba-speaking people across the savannah-forest transition of what is today western Nigeria and central Benin were notably inclusive of migrant and refugee communities in pre-colonial times). It is important to emphasise the dynamic character of tenure arrangements. These evolve in response to socio-economic circumstances, though in some cases they can be frozen through ill-planned government interventions in the customary sector. The evolution of the institution of land tenure may adversely affect soil fertility. In the case of the transitional zones of Benin and Ghana (Adjei-Nsiah et al., 2006) symbolic sharecropping and labour-for-land arrangements in Ghana and Benin have contributed towards the evolution of individualistic, money-based, tenurial arrangements which have had a negative effect on soil fertility maintenance. Among forces driving changes in land tenurial arrangements, Biaou (1993) indicated changes in social organisation, population pressure (land/labour ratio affects whether there are sharecropping or monetary arrangements) and economic factors. It is also possible that changes in land tenurial systems induce changes in social organisation and economy.

While some economic studies claim that in the case of private property, land security is a key factor in allowing producers to obtain credit and access innovation (Manyong and Houndékon, 2000; IAC, 2004), this relation is less clear than such theories suggest. It is argued that borrowing of land (métayage in French), a practice relatively widespread in many parts of Benin, is a serious threat to sustainable land use (Edja, 2001) because this practice does not give guarantees to the land user to invest in long-term land management on land belonging to somebody else.

Rapid population growth, widespread poverty, persistent food insecurity and alarming rates of environmental degradation have fuelled a debate on land tenure systems and land reforms in Africa. However, there seems to be no consensus on the type of tenure that would yield greater security and efficiency in terms of agricultural productivity or natural resource management (De Zeeuw, 1997). Moreover, the lack of adequate land regulation and administration has been a constraint to the implementation of new land policies. Yet, in the midst of these unresolved controversies, many African countries have embarked on state-led land reform programs aimed at providing equity, reducing poverty, fostering economic growth and improving the management of natural resources. Most of these reforms have yet to bring about the expected results. The state's ideology (the land belongs to the person who works it –

the theory of Locke) can have a negative effect on the willingness to apply long-term fallowing, because bush-fallow may then become no-man's land.

The state now has often stepped aside or given powers to decentralised powers. Administrative decentralisation appears as an opportunity for more democratic forms of localised resource management because it modifies the balance of power and creates new local authorities endowed with a legal competence (Ribot, 2002). Because of its political nature, administrative decentralisation is not sufficient to ensure that elected representatives are accountable in front of their electors. In West African French-speaking countries, Benin included, the Plan Foncier Rural (PFR) (Lavigne Delville, 2002a) has attempted to guide land reform but raised more questions than it answers. Analysis based on a number of studies following-up on these PFRs suggests that for different reasons, such PFRs cannot currently be considered a panacea (Lavigne Delville, 2002a). PFRs have difficulties to take into account the reality of local land systems, especially the challenges they raise in terms of institutions. They distort the substance of local rights as soon as they try to capture and stabilise them (for example they deny subsidiary rights of women). Therefore there is a need to explore the possibility to create new local institutions regulative of access to land. Such institution will seek to guarantee rights to both migrants and landowners, and at the same time create incentives for land users to invest in long-term soil fertility management. This thesis will explore some of the ways in which technology can be introduced within tenurial frameworks applicable to the transitional zone of Benin, where fertile land is becoming scarce. Food output has increased but without compensating investment in soil fertility management.

Relevance of soil fertility management technologies in smallholders' farming systems of Benin

In recent years a number of technologies have been developed to improve the productive capacity of tropical soils. These technologies have been tested and made available to the extension services through a techno-economic approach known as transfer of technology (Versteeg and Koudopon, 1990; Houndékon *et al.*, 1998; Vissoh *et al.*, 1998; Floquet, 1998; Agoudoté, 1999; Douthwaite *et al.*, 2002). These technologies include mineral fertiliser, soil organic matter improvement (compost, farmyard manure, mulching with crop residue, cover crops, agro-forestry etc.), and crop rotation.

A general observation is that farmers do not accept these improved soil fertility management technologies readily, because scientists have overlooked labour constraints, financial constraints, lack of control over markets, tenure contracts, land scarcity, and the need to forego harvests, etc. Adégbidi *et al.* (2000) concluded that technology development has been ineffective and inefficient in the case of Benin for several reasons:

- *economic aspects*: the technological package currently introduced is expensive with regard to advantages (profits) expected, the low and unpredictable agricultural produce prices in the market, and high opportunity cost;
- unstable *politico-institutional context*: the frequent change of agricultural policy options (*e.g.* end of projects often without support action), structural adjustment, etc.;
- incomplete *technology*: technologies introduced (*e.g.* cover crop, compost, farmyard manure, etc.) are sometimes incomplete without accompanying measurements such as input equipment and improved market opportunities for increased agricultural output, etc.;
- unfavourable *social context*: this includes the illiteracy of many smallholder farmers, which makes it hard for them to appreciate technology principles or instructions, and sometimes acute local labour shortages, inhibiting adoption of labour-intensive improved soil fertility management requirements;
- local *social divisions (especially between landowners and migrants) in the community, and the weak position of migrants with regard to land tenure*: migrants need tenure security in order to invest in agriculture, and in particular to invest in efforts and inputs required to adopt durable soil fertility management practices.

It is now generally recognised that improved practices need to be designed with the participation of farmers, on the basis of the constraints which they themselves perceive. Soil fertility management demands a lot of practical skills (Defoer, 2000). As soil fertility management is both a technical and social issue, ‘hybrid’ research methodologies adequate both at the level of explanation (in terms of causal mechanisms) and in terms of meanings to social actors (Perri 6, 2006) are needed. One way in which such hybrid research explanations can be generated is through fully involving farmers in the research process, and giving them opportunities to influence the research agenda and methodologies to be used, under a general rubric of democratisation of science. The point to be explored in this thesis is soil fertility management technology, in the end, can be incorporated within local institutional frameworks. The technology needs to be correctly designed (the basic causal mechanisms must be understood according to scientific criteria) but at the same time people have to make sense of what is going on through their own framework of ideas. The kind of participatory research is intended not only to build upon correct causal mechanisms but also to build mutual understanding between technologists and farmers about the role of technological interventions, to ensure that these interventions bind themselves effectively to emergent local institutions, such as land tenure institutions.

Soil fertility and soil biology

In natural ecosystems, the soil fauna plays an important role in nutrient cycling and the maintenance of soil health (Sanchez *et al*., 1989). Earthworms, termites and ants contribute to the maintenance of a relatively high soil porosity by digging galleries. Earthworm casts at the soil surface regulate soil porosity, as a volume of voids equivalent to that of casts is created inside the soil (Birang, 2004). Earthworms also contribute to soil aggregation through the production of casts (Blanchart *et al*., 1997). Earthworms increase the clay content of surface soil by selectively bringing up soil richer in clay (Birang, 2004). Earthworms alter the pH from slightly acidic to basic, mainly by bringing calcium to the surface. They enrich the soil with organic C, total N, Ca, Mg, K and Na as result of digesting material and faeces and/or saliva in their workings at the surface. In general, farmers perceive earthworms as an indicator of soil fertility, not necessarily as organisms that create or maintain soil fertility (Ortiz *et al*., 1999).

Almost all tropical crops are mycorrhizal, and many, if not most, are (strongly) dependent on and responsible to arbuscular mycorrhizas (Cardoso and Kuyper, 2006). The mycorrhizal association has received attention as part of an increasingly well-supported paradigm that considers an active and diverse soil biological community as essential for increasing the sustainability of agricultural systems. Mycorrhizas are multifunctional (Newsham *et al*., 1995), potentially improving physical soil quality (through the external hyphae), chemical soil quality (through enhanced nutrient uptake of immobile nutrients, especially P, but also micronutrients such as Zn and Cu), and biological soil quality (through the soil food web) (Cardoso and Kuyper, 2006).

Improving processes of agricultural research: Convergence of Sciences (CoS) approach

The present study fits within a larger programme known as Convergence of Sciences: inclusive innovation technology processes for integrated soil and crop management (CoS), operating in Benin, Ghana and the Netherlands. CoS takes off from the observation that West African farmers derive sub-optimal benefits from formal agricultural science (Hounkonnou *et al*., 2006). Several studies (Chambers and Ghildyal, 1985; Chambers and Jiggins, 1987; Millington *et al.*, 1989) have recognised that delivery of science-based technologies to end-users fails because no insufficient account is taken of human factors in technology use. Therefore, there has been an interest in what is (in Dutch academic circles) known as the *beta/gamma* approach (Röling, 2000; Giampietro, 2003) to agricultural science. *Beta* stands for the natural sciences and *Gamma* for the social sciences. Together, *Beta* and *Gamma* sciences are becoming increasingly involved in the interactive design of technology, farming systems, knowledge systems, natural resource use and other forms of land use negotiation (Leeuwis, 1999).

The philosophy of CoS is based on the principle that innovation is the emergent property of the interaction among different stakeholders in agricultural development. Convergence should take place between natural and social science and between societal stakeholders (including farmers) and scientists (Nederlof *et al*., 2004; Hounkonnou *et al*., 2006). Therefore, CoS tries to understand the conditions for technological and institutional innovation (in terms of cost-effectiveness, persistence, and empowerment of resource-poor farmers). It aims firstly, to determine the type of research required and the necessary political, economic and social conditions for success, and then to support the embedding of technologies within appropriate organisational frameworks. Secondly, CoS seeks to provide pathways towards a more efficient and effective model for agricultural technology development, *e.g.* through methodology and curriculum development. The CoS programme included technographic and diagnostic studies to make pre-analytical choices explicit (Giampietro, 2003; Röling *et al*., 2004).

Technographic survey explores the innovation landscape, by looking at the technological histories, markets, institutions, framework conditions, stakeholders, and contextual factors at both macro and micro levels (Richards, 2001; Röling *et al*., 2004; Projet CoS, 2004). The context of a crop or a policy is indicated in order to facilitate the choice of research area or theme. The choice for a research area in this way is made explicit. The technographic studies observed that farmers, both in Ghana and Benin, were using extensive cassava cropping (known in French as *jachère manioc*, literally cassava fallow) as strategy for restoring soil fertility. Some scientists considered this claim implausible, so it seemed interesting to dig deeper into a practice farmers considered effective. The inclusion of soil fertility as a subject by itself was based on the conclusion that soil fertility was a domain for which innovations were required, independent of specific crops.

The West African context required careful diagnostic studies to be able to design useful agricultural research. In order to ground research in farmers' opportunities and needs, emphasis is put on a process determining research priorities with the community of farmers. To test the validity of farmers' claims, we agreed to investigate the potential of extensive cassava crop rotations as a means to restore soil fertility and maintain adequate crop yield. As soil fertility problems cannot only be solved based on technology, the social arrangements and institutions (*e.g.* adapted land-tenure contracts, new marketing channels, and novel ways of mobilising labour) were also scrutinised as of potential importance.

Context of the study and research process

The present PhD study attempts to reconceptualise both the problem of soil fertility decline and the solution to be applied. Mediation between indigenous and scientific knowledge in soil fertility management is needed. An approach based on participatory on-farm research and experiential learning allows the development of more effective and efficient systems and approaches for participatory technology development. Developing and testing farmers' theories using scientific tools (*i.e.* linking interpretive and explanatory accounts) was a major issue of this research. In fact, the study builds on a methodology in which knowledge acquisition is dominated by and organised around the development of realist propositions linking mechanisms, context and outcomes (Pawson and Tilley, 1997). As Pawson & Tilley argue, one of the hardest tasks in applied science is developing sufficiently rich sets of context-mechanism-outcome configurations to merit scientific data collection, analysis and testing. In this thesis the ideas of farmer-experts have been engaged to help assemble testable context-mechanism-outcome configurations regarding soil fertility management. The research process comprised several steps: planning, implementing and managing collaborative on-farm experiments, monitoring and evaluation, and analysis and feedback.

Planning

Tools and concepts were provided in order to explain to farmers scientific concepts such as treatment (experimental variable), replication and statistical analysis. Replication was explained with reference to soil micro-variability which is well known to farmers. However, we did not just do the experiments that farmers wanted, but engaged in a critical dialogue, in which farmers and researcher challenged each other to agree on a set of experiments (democratisation of science). On the basis of the objectives of the agreed experiments, we discussed within a stakeholder learning group (SLG), formed after the diagnostic study what, how and when to evaluate the trials. The SLG helped determine experimental variables, the number of replications, criteria for evaluating results, data to be collected and finally, farmers' perception, knowledge and predictions concerning the likely outcome of the experiment.

Implementing and managing the experiment (acting phase)

A 'co-operative' on-farm experimental protocol (co-research) was adopted and implemented by members of the SLG as planned. The cost of inputs was covered by the researcher but the weeding and harvesting were undertaken by the members of the SLG.

Monitoring, evaluation and reviewing

Based on the research objectives, we jointly evaluated the results of the co-operative on-farm experiments. Farmers' attitudes towards and perception about the performance of the innovation were collected and analysed in order to evaluate whether they did change their cropping system. Monitoring and evaluation were also mechanisms for building mutual accountability among partners.

Analysis and feedback

At the end of each co-operative on-farm experiment, conclusions were drawn and discussed with the members of the SLG. Analysis included questions related to what had been learnt and further implication of the finding in term of improving farmers' cropping system.

Description of the study area

The study was carried out in the sub-prefecture ('Commune') of Savè located in the transitional zone of Benin between 7°42' and 8°45'N and 2°15' and 2°45'E. It is characterised by a Guinea-Sudan climate with unimodal rainfall. The rainy season lasts from April to October. The annual rainfall is about 1100 mm (Savè weather station, 1974-2004). The average yearly temperature is about 27.5 °C with little variation from year to year. The area is essentially dominated by tropical ferruginous soils (Dubroeucq, 1977) originally from Precambrian crystalline rocks (granite and gneiss). The soils are deep without laterite and often have a somewhat good inherent fertility. The total population is about 68,000 inhabitants. Population density averaged 30 persons km^{-2} (INSAE, 2004). Migrants constitute 37% of this population. Migrants started to establish in the transitional zone of Benin before 1960 due to the introduction by the French colonial regime of certain cash crops (such as tobacco, cotton, and groundnut) that required intense labour. Some migrants came from an infertile mountain region in the north, where land was in short supply. More recently, some migrants have started to move in from over-populated regions of sandy soils in the forest zone to the south.

Migration, a livelihood improvement strategy, can also be seen as a soil fertility management strategy in these infertile areas where soil fertility is an acknowledged problem. It contributes to both the emigration and the immigration zones. In the zone where migrants once lived, pressure on land reduces, but labour availability is also reduced. If migrants send back remittances, it improves the welfare of the remaining family members. In the zones of immigration, higher population densities lead to increased pressure on land, but there is also increased labour availability. Migrants have contributed to the zone of immigration through bringing with them new seeds and cropping practices, such as cotton rotated with cereals, rice and yam cultivation in flooded zones, maize intercropped with sorghum, intensification of cotton production, etc.

Crop sequences in the research area vary according to soil type. Four types of crop sequences were mentioned by the farmers: (1) yam, maize or maize/groundnut, cowpea, and last with maize/cassava or cassava/groundnut; (2) cassava, maize/groundnut, and last with maize/cassava; (3) cassava or egusi melon (*Citrullus* spp. and *Lagenaria* spp.), maize/groundnut or cotton, groundnut/maize or cotton, and last with maize/cassava or egusi melon; (4) cotton, maize or maize/groundnut, egusi melon or cotton, and last with cassava. After three years of cropping, the indigenous populations usually plant cashew, a perennial crop, on exhausted land. Migrants do not have this option since they are not permitted to plant perennials, because this could establish land ownership claims. Intercropping is commonly practised by the local population throughout the whole area. Three intercropping systems with maize exist: (1) with grain legumes, (2) with sorghum and (3) with cassava.

Aim and outline of the study

The study aimed at contributing to better local resource management and improving farmers' management practices with regards to soil fertility. It does so by linking farmers' perceptions and interpretations of biological processes related to soil-plant relationships with explanations based on scientific theories. It also aimed to open a pathway for farmers to approach soil fertility phenomena as evidence of processes to be managed. This takes them beyond interpretation – the decoding of signs that something is amiss. Chapter 2 deals with the results of the diagnostic study aiming to determine research priorities with the community of farmers. Perceptions of farmers on the causes and consequences of land degradation and corrective actions for sustaining soil fertility were studied.

Chapters 3 - 5 describe results of interactive research based on co-operative on-farm experiments. In chapters 3 earthworm activities in extensive cassava and egusi melon cropping systems are described. The chapter reveals that farmers are knowledgeable on the role of earthworms.

Chapter 4 describes mycorrhizal incidence on cassava and subsequent maize in relation to nutrient(s) limiting crop production in a cassava-maize rotation system. A nutrient balance was also made for the maize crop. In chapter 5 an attempt is made to study the effect of farmers' mineral fertiliser management strategies and land use types on subsequent maize yields and nutrient uptake. I examine whether alternative fertiliser application practices to cotton can be an alternative to sustain subsequent maize yields and achieve balanced plant nutrition. Farmers' perceptions on the role of urea and NPK-SB fertiliser, and knowledge on the residual effect of previous cotton fertiliser are described.

Chapter 6 evaluates the relative impact of the learning and the co-operative on-farm experimental processes in terms of two dimensions of capital (human and social) with regards to soil fertility management. I also analyse the limitations and strengths of the co-research framework in the perspective of possible subsequent scaling up of CoS activities. I discuss how scientists and farmers could better interact for joint learning and co-construction of knowledge.

Land tenure is an important source of tension over land use between landowners and migrant farmers in the transitional zone of Benin. In chapter 7, I present the evolution of tenure arrangements and the factors that diminish mutual trust. I also present the methodological approach used in the negotiation process and the main outcomes of the tenurial arrangement using community-based and multi-stakeholder platforms. With the alternative arrangement negotiated, great importance is given to monitoring. In the process, science plays a potential role in increasing productivity of the land – devising win-win situations - so that both parties (migrants and landowners) can profit from the new arrangements, and in monitoring.

In the final chapter (general discussion) I evaluate the main findings of the foregoing chapters in a broader context and suggest some directions for further research.

Chapter 2

Sustainable soil fertility management in Benin: learning from farmers

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Chapter 2

Sustainable soil fertility management in Benin: learning from farmers

Abstract

The perception of farmers from the Atacora and Savè zones of Benin was studied about the causes and consequences of land degradation and corrective actions for sustaining soil fertility. Research methods in this diagnostic study included group discussions, using non-standardized, unstructured interviews and participant observations. Farmland degradation leading to declining yields, and land tenure arrangements were identified as the main constraints on the sustainability of agriculture. In both regions the farmers stated that climatic changes (less and more irregular rainfall), run off, erosion, and overexploitation of farmlands caused land degradation. Soil fertility status was assessed on the basis of dicotyledonous weeds, soil texture and colour, and soil fauna (earthworms casting activity). Farmers have adapted their cropping systems to the local environment by developing traditional and new strategies and activities that could contribute to maintain or enhance crop productivity. These strategies include animal manure, inorganic fertilizer, crop rotation, a five-year fallow, extensive cropping systems with cassava or egusi melon, and emigration. Land tenure arrangements between landlords and migrants affect strategies that can be applied to maintain soil fertility. The importance of building mutual trust and the need to experiment with different land tenure arrangements are indicated. A framework for interactive research where knowledge is collectively generated is proposed in order to test the effectiveness and applicability of some of these local innovations not yet well understood by conventional science.

Keywords: soil degradation, indigenous knowledge, land tenure arrangement, social dilemma

Introduction

Worldwide, soil fertility decline has become a major concern of policy makers (Gray and Moran, 2003). The Neo-Malthusian assumption is that soil fertility decline is an inevitable consequence of population growth and mismanagement of land resources. However, an alternative approach from Neo-Boserupians claims that population growth could, under certain conditions, result in less erosion, more forest cover and increased soil fertility (Tiffen and Mortimore, 1994; Fairhead and Leach, 1995; Leach and Fairhead, 2000a). Apparently, the nature and extent of land degradation are imperfectly understood. Many technological and institutional innovations that can solve soil fertility degradation have been developed and yet, these innovations do not generally appear to be successful (Biot *et al*., 1995; Floquet, 1998; Versteeg *et al.*, 1998; Alohou and Hounyovi, 1999; Wennink *et al*., 2000; Douthwaite *et al*., 2002). The local people often reject proposed technologies that have been imposed from outside and delivered top-down. The main reasons are a lack of fit between the proposed techniques and the local farming systems and farmers' livelihood strategies, limited availability and accessibility of external inputs, lack of markets access, inappropriate land tenure conditions and finally, lack of participation by land-users in designing and implementing technologies. Instead, farmers adopt their own individual and collective approaches that have in the past resulted in sustainable livelihood practices (Biot *et al.*, 1995). The challenge is to listen and to learn from farmers' own knowledge. There is ample room for approaches that transcend the analytical dichotomy between scientific and indigenous knowledge in relation to West African farming systems and for a convergence of formal and informal sciences (Richards, 1985; Leach and Fairhead, 2000b).

Farmers' soil knowledge offers a different set of temporal and spatial scales with regard to land use, which has important implications for sustainable agriculture (Brouwers, 1993; Sandor and Furbee, 1996). Local people have significant knowledge of soils and environments, acquired by experiences that have been tested by many generations living close to the land (WinklerPrins, 2003). Understanding farmers' indigenous knowledge and practices on soil fertility management means understanding local realities, which is crucial for the potential success or failure of any type of agriculturally-based development (WinklerPrins, 2003).

Farmers in the Atacora region of Benin are facing soil degradation (Adegbidi *et al*., 1999; Mulder, 2000). Nutrients are lost due to the relatively hilly relief with slopes of about 15%. Agricultural intensification reduces soil organic matter, which leads to nutrient depletion thus threatening the sustainability of the farming systems (Saïdou *et al.*, 2003). In contrast, farmlands in the Savè region are more fertile and the cropping systems are still based on shifting cultivation. Nowadays there is a large influx of migrants (Igue, 1983; Edja, 1996; LARES., 2000; Mulder, 2000) from Atacora and the southern regions of the country where farmers are running away from soil degradation and nutrient depletion. While migration may be a novel social strategy that releases pressure on the land in one area, it may simultaneously increase pressure on the land and on social relationships (insecure land tenure) elsewhere. Insecure land tenure encourages soil-mining practices, which reduce the long-term productivity of the land. Not much is known about the specific details of farmers' knowledge in relation to key soil fertility management decisions.

The present diagnostic study is an entry point for Convergence of Sciences programme (Röling *et al.*, 2004) experimenting with an interactive approach with farmers to tackle the soil fertility depletion problem. In this process, the development of a systematic bottom-up approach for innovation development and dissemination is one of the main issues. It follows on the technographic study (Richards, 2001) carried out from October to December 2001 in relation to cotton, sorghum and cowpea (Projet CoS, 2004).

The aim of this diagnostic study is to describe and compare the Atacora and Savè regions in Benin in terms of (1) farmers' perception and knowledge about causes and consequences of land degradation, (2) farmers' criteria and approaches for soil classification and differentiation, (3) corrective actions for sustaining soil fertility management based on interactive research and farmer experimentation, and (4) a framework for understanding the social side of the land (tenure arrangements). At the end, the paper takes a reflexive stance, when it looks back at the diagnostic study and critically looks at the choices that have been made to arrive at the next phase of research.

Methodology

The study area

The diagnostic study was carried out in two regions, Atacora and Savè

Atacora

The Atacora zone is dominated by the Atacora mountains, with altitudes varying from 400 m in the south to 650 m in the north (Faure, 1977). The region is close to the Sahelian zone. The climate is tropical, of the Guinea-Sudan type characterized by strongly contrasting seasons with a single rainy season from mid-April to mid-October followed by a dry season from November to March. The annual precipitation varies from 1000 to 1300 mm (Natitingou weather station). The average annual rainfall over the last 30 years was somewhat lower than the long-term average. Farmers claim that the climate is changing (less and more irregular rainfall). But the available data do not permit to determine whether this is true or whether agricultural intensification leads to loss of soil organic matter and a lower water-holding capacity, which has similar effects on agricultural yields as a drier climate. The average yearly temperature is about 26.5 °C. Most of the soils are tropical ferruginous soils (Faure, 1977) classified by FAO as Ferric Lixisols (FAO, 1990). The soils are limited in depth by gravel and lateritic formations and are suffering from crusting and compaction. With few exceptions, the soils have a low inherent fertility. The vegetation is open savannah. There are large differences in population density within the area (9 inhabitants km^{-2} in Bassila in the south against 49 and 62 inhabitants km^{-2} in Boukoumbé and Kobli, respectively) (INSAE, 1994). The population consists largely of farmers (92%). Most of the indigenous population belongs to the *Ditammari* ethnic group. Other major ethnic groups are the *Yom* (in the south), *Berba* and *Waama* (in the central zone), the *Bariba* (in the north-east) and the *Peulh* (herdsmen), who are scattered over the entire region. As a consequence of the relatively low inherent fertility and the rather high population pressure, the region experiences a pressure on the land especially in the hilly zones. So the Atacora region is an emigration area, with mainly younger people leaving for the Savè region.

Savè

The Savè region too is characterized by a Guinea-Sudan climate with an unimodal rainfall distribution. The rainy season is from April to October. The average annual rainfall over the last 30 years is about 1100 mm (Savè weather station). The average yearly temperature is about 27.5 ^{o}C with little variation from year to year. Like in the Atacora region, the area is essentially dominated by tropical ferruginous soils (Dubroeucq, 1977), originally from Precambrian crystalline rocks (granite and gneiss). In contrast with the Atacora region, the soils are deep without laterite and often have a somewhat higher inherent fertility. Land is not yet a limiting factor. The natural vegetation is of the mosaic sub-humid savannah type. Population density is comparable to the one of Atacora, with about 22 inhabitants km^{-2} (INSAE, 1994). The indigenous population is composed of the *Tchabè* and the *Peulh*. Since 1975, there has been an influx in the region of migrants from Atacora and the Abomey Plateau. This has led to the emergence of new communities in the area such as the *Ditammari*, *Yom* and *Waama* (from Atacora), the *Fon* (from Abomey plateau) and the *Idatcha* from Dassa Zoumè and Glazoué.

Research activities

The diagnostic study was carried out during the cropping season (June - November) of 2002. It comprised two phases, an exploratory survey and an in-depth survey (Fig. 1). The exploratory survey was carried out in seven districts: Boukoumbé, Matéri, Ouaké and Kouandé in north-west Benin (Atacora region), N'dali and Tchaourou in mid-east Benin (the south Borgou region) and Savè in the south-eastern of Benin (Savè region). They were selected in close collaboration with the various actors that are active in these regions (extension service CARDER, NGOs and R&D). In total, 15 villages (Fig. 2) were studied. The introduction of the researcher in each village was facilitated by the local extension service (CARDER) and the farmer organization (Groupement Villageois - GV). The selection was based on accessibility, distance to the major nearby town, relevance of land degradation problems, and land tenure. The in-depth survey was subsequently carried out in seven villages: Tchato, Tchanhoun-Cossi, Gnalo, Madjatom, Boubouhou, Ouoghi central and Ouoghi gare. Their selection was based on accessibility, farmer availability and interest to the project (judged from their participation in the group meetings and the critical dialogues engaged during each meeting), relevance of land degradation problems and related soil fertility management strategies adopted, socio-economic and cultural opportunities, and land tenure arrangements.

Field and participant observations (during transect walks), focused group discussions (taking gender into account), non-standardized and largely unstructured interviews with individual farmers, farmer organizations and key informants (researchers, project workers, representatives of NGOs, and extensionists) were used in data collection. In Savè region, landowners and settlers were added to the focus groups in order to assess land tenure issues.

Field observations were used to supplement and validate the data collected and the information gathered during the group discussions. During the transect walks, the different soil types identified by the farmers were sampled (0–20 cm). Also weeds and plant parts used by the local people as indicators of soil fertility were collected. They were identified at the National Herbarium of the University of Abomey-Calavi in Cotonou. The soil samples were analysed by the Laboratoire des Sciences du Sol, Eau et Environnement (LSSE/INRAB) in Cotonou. Analyses included particle size distribution (by sieve and pipette method after removal of organic matter, carbonates and iron oxides), pH-H_2O (using a glass electrode in 1:2.5 v/v soil ion), organic carbon (Walkley-Black, wet oxidation procedure), and total nitrogen (Kjeldahl method). The results of the analysis were presented at a feedback session in the villages in order to strengthen contacts with farmers for the continuation of the research programme.

Results

Farmers' soil classification and inherent soil fertility assessment

In the Atacora and Savè regions some local soil names refer to the texture. The names *kubirgu* in Ditammari, *biyalic* in Biali, *kagniga* in Bufalè and *ilè ignin* in Tchabè all literally mean sandy soil. In the Atacora region also the gravel content (> 2 mm) is used as criterion for soil classification. The names *fatan'fa* in Ditammari, *sage* and *whanga* in Biali, *kuluri* in Lama and

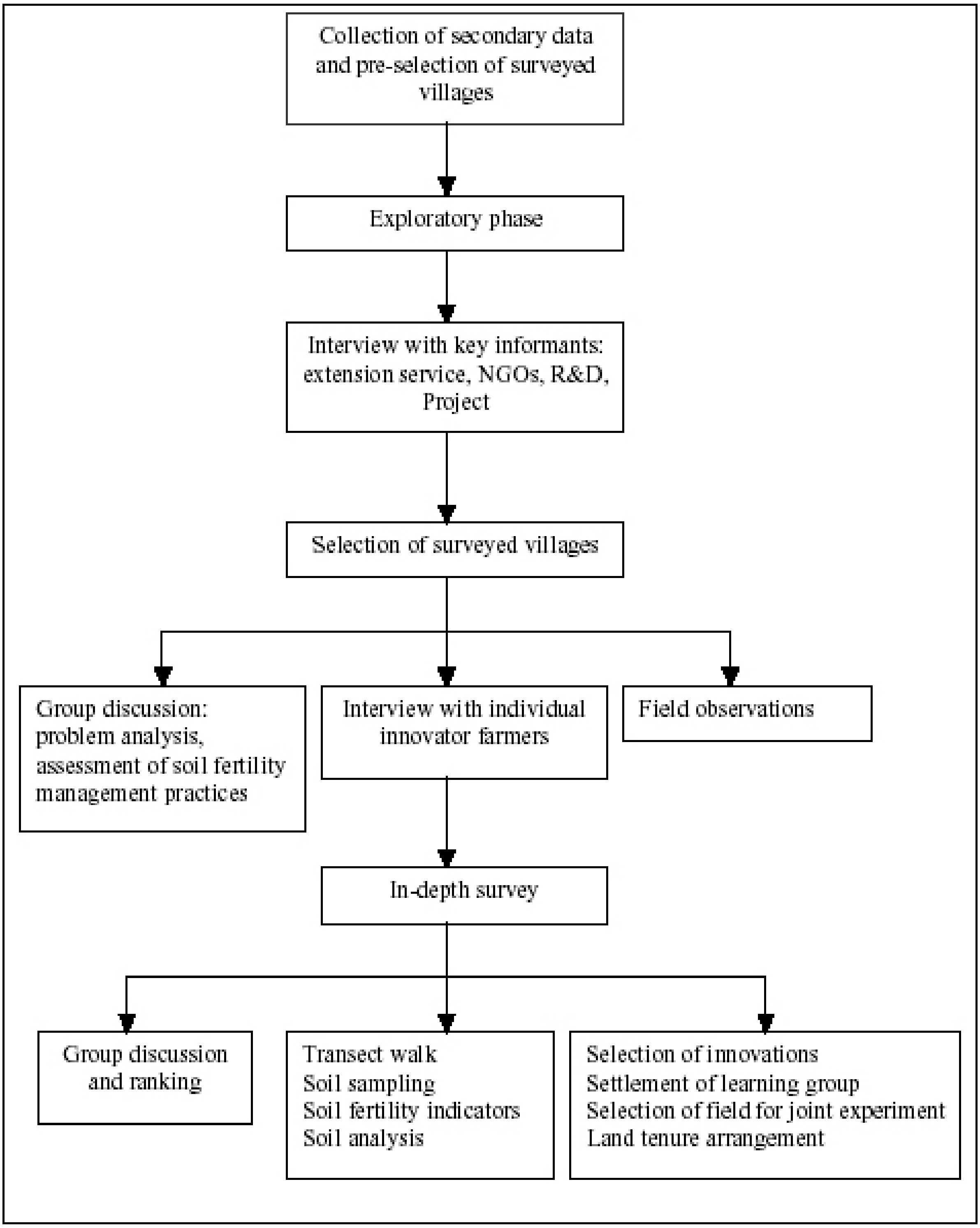

Figure 1. Diagram showing the research process.

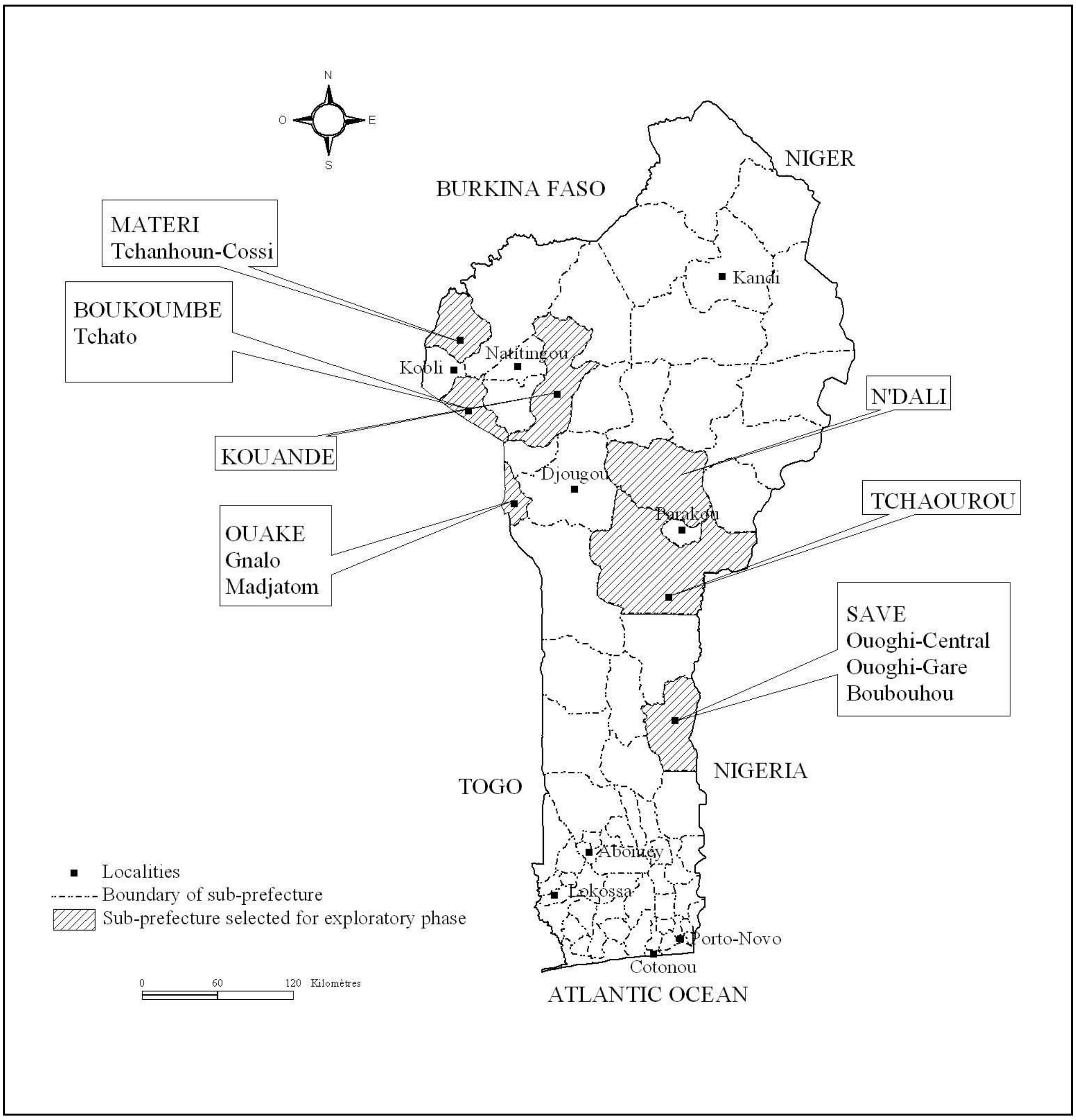

Figure 2. Map of the republic of Benin with the districts (hatched; names in capital letters) and the villages (small letters) where the diagnostic study was carried out.

tèyassikum in Bufalè all literally mean gravely soil. Most of the soil textures assessed by the farmers closely agree with those of the International Soil Science Society (ISSS) (Table 1).

In both areas, farmers' indicators for assessing a healthy or fertile soil are mainly based on:

1. Occurrence of specific dicotyledonous weeds;
2. Soil texture and hydrological quality;
3. Soil workability;
4. Soil fauna, especially earthworms.

These indicators are used by farmers to make decisions on what to grow and on the type of soil fertility management required. In the cultivated fields, farmers assess soil nutrient status on the basis of crop behaviour (growth and development) and leaf colour. In both regions they argue that pale and yellowish plants reflect some 'food' (nutrient) deficiencies. Farmers in the Savè region also use variations in soil colour as an indicator of declining fertility. Such a change in colour always occurs on the *ilè dudu* soils, which become less dark after continuous cropping.

The soil evaluations by farmers were compared with the results of soil chemical analyses (Table 1). The soils in both regions are mostly acid to neutral: pH-H_2O ranging from

Table 1. Selected physical and chemical properties (0 – 20 cm) and fertility indication of the soils named by the farmers (in italics) in the Atacora and Savè regions, Benin. The local language is placed in parentheses.

Soil name/ language	ISSS texture	Particle size (< 2 mm) (%)			Gravel (> 2mm) (%)	Fertility indication	pH (H_2O)	Total N (g kg^{-1})	Org. C (g kg^{-1})
		Clay	Silt	Sand					
Fatan'fa (Ditammari)	Very gravelly sandy loam	7.8	26.1	66.1	64.5	Fairly fertile	5.9	1.2	9.9
Fagnan'fa (Ditammari)	Gravelly sandy loam	8.8	28.4	62.8	43.0	Fertile	6.4	1.2	13.8
Kubirgu (Ditammari)	Gravelly sandy loam	6.9	28.1	64.9	33.3	Mediocre	5.9	0.6	6.6
Sage (Biali)	Very gravelly sandy loam	8.6	20.5	70.8	58.0	Fairly fertile	6.2	0.9	9.5
Pahun (Biali)	Silt loam	14.9	57.7	27.4	2.2	Fertile	6.0	1.3	15.6
Biyalic (Biali)	Sandy loam	7.0	22.4	70.5	18.7	Mediocre	5.6	0.6	5.2
Whanga (Biali)	Very gravelly sandy loam	10.2	34.6	55.3	63.1	Fairly fertile	5.5	0.8	10.2
Kagniga (Bufalè)	Loamy sand	4.8	11.5	83.8	1.4	Fairly fertile	5.7	0.3	2.7
Petaka (Bufalè)	Gravelly sandy clay loam	23.6	18.2	58.2	42.0	Fairly fertile	6.0	0.6	5.8
Tèyassikum (Bufalè)	Very gravelly loamy sand	8.8	9.0	82.2	56.3	Fertile	5.6	1.3	9.8
Tèkpê têkun (Bufalè)	Loamy sand	6.1	11.6	82.3	1.4	Very fertile	6.2	0.9	8.9
Katchika (Lama)	Sandy loam	16.5	7.4	76.1	2.5	Fairly fertile	5.0	0.4	3.9
Kangniga (Lama)	Sandy loam	11.4	9.1	79.5	0.9	Fertile	5.5	0.6	5.8
Puturi (Lama)	Gravelly loamy sand	6.5	11.9	81.6	32.8	Very fertile	7.1	1.2	7.5
Kuluri (Lama)	Very gravelly loamy sand	7.5	8.8	83.7	57.1	Fairly fertile	5.4	0.3	2.8
Kpankpandè (Lama)	Sandy loam	13.4	8.0	78.6	2.0	Mediocre	5.2	0.1	0.6
Ilè dudu (Tchabè)	Loamy sandy	7.6	11.4	81.0	0.9	Fertile	5.8	0.8	8.1
Ilè kpukpa (Tchabè)	Loamy sandy	6.7	11.1	82.2	1.7	Very fertile	5.7	0.7	7.1
Ilè ignin (Tchabè)	Loamy sandy	5.6	7.5	87.8	0.8	Fairly fertile	6.0	1.2	11.9

5 to 7.1. The most fertile soils concluded from high contents of total nitrogen and soil organic matter were the *fagnan'fa* (which in Ditammari literally means soil without stones and easy to work), *pahun* (in Biali), *tèyassikun* (in Bufalè), *puturi* (in Lama) and the *ilè dudu* (in Tchabè). On the other hand, the poorest soils were *kubirgu* (in Ditammari), *biyalic* (in Biali), *kagniga* (in Bufalè), *kpankpandè* (in Lama) and *ilè kpukpa* (in Tchabè). The results from soil analyses were mostly similar to the soil fertility evaluations by the farmers except for the ranking made in Savè where the *ilè kpukpa* was supposed to be a fertile soil. This contrasting result may be explained by the fact that this soil was sampled in a one year old fallow field invaded by spear grass (*Imperata cylindrica*), which is an indicator of soil degradation.

In both regions the grass species *Andropogon gayanus,* and the dicotyledonous species *Indigofera secundiflora* (in Atacora) and *Chromolaena odorata* (in Savè) are recognized as indicators of fertile soil, whereas *Hyptis* spp., *Striga hermonthica* and *Spermacoce filifolia* (in Atacora), indicate infertile soils. The abundance of witch weed (*Striga hermonthica*) in Atacora region or spear grass (*Imperata cylindrica)* in Savè (even on fertile soils) forced farmers to abandon their land (Vissoh *et al*., 2004).

Cropping systems

Crop sequences vary according to region and soil type. Land freshly cleared from forest is cropped for up to four years. In Atacora the first crops grown are: yam, or cotton followed in the second year by groundnut; maize/sorghum or cowpea. In the third year groundnut is grown or the land is left fallow (mostly on sandy clay soils). Finally, in the fourth year maize/sorghum or cassava is grown. In the Savè region, four types of crop sequences were mentioned by the farmers: (1) yam - maize or maize/groundnut – cowpea - maize/cassava or cassava/groundnut, (2) cassava - maize/groundnut - maize/cassava, (3) cassava or egusi melon (*Citrullus* spp. and *Lagenaria* spp.) - maize/groundnut or cotton - groundnut/maize or cotton - maize/cassava or egusi melon, (4) cotton - maize or maize/groundnut - egusi melon or cotton – cassava. After three years of cropping, the indigenous populations mostly plant cashew trees. Such a practice may be related to the land tenure arrangement as planting trees often means laying a claim on the land.

The local population in both regions practises intercropping. The field is managed on the basis of the farmer's skill, *i.e.*, farmers' knowledge about the performance of the plant and the soil. There are three intercropping systems with maize: (1) maize with grain legumes, (2) maize with sorghum, and (3) maize with cassava. Farmers know the difference between maize and grain legume roots but they do not attach importance to the legume roots, *i.e.*, they do not know the connection between roots, root nodules and nitrogen fixation. However, farmers claim that legumes in the rotation system enhance soil fertility.

Some of the reasons for intercropping relate to the sustainability of the cropping system. However, socio-economic reasons can drive intercropping practices too. Market, food security and the need for cash money influence a farmer's decision whether he/she will intercrop maize with sorghum, with legumes or with cassava. If maize is intercropped with sorghum or cassava, maize is sown first and harvested earlier than the companion crop, allowing the sorghum or cassava plants to develop. On the other hand, maize and legumes are sown almost at the same time but at different densities based on farmer's objectives. In both regions, cotton is mostly mono-cropped and the subsequent crop is always maize or maize/sorghum. In this cropping pattern the subsequent cereals benefit from the residual effect of inorganic fertilizer applied to cotton (150 kg ha^{-1} of NPK-SB 14-23-14-5-1 plus 50 kg ha^{-1} of urea as recommended by the extension service).

In the Atacora region fallow land is rare because of the strong pressure on the land. But in the Savè region, a fallow period of 3 to 5 years is observed. The sorghum stover and the cotton stalks are burnt whereas the leaves and the roots of cowpea are left to decompose in the soil. Groundnut, bambara groundnut, soybean and egusi melon residues are left in the field and incorporated in the soil during ridging. In the dry season, herdsmen are allowed to graze their cattle in the maize and sorghum fields where part of the stover is consumed. Such practice can be considered as a net nutrient loss because the cattle do not spend the night in the field and so do not fertilize the soil with their dung.

In Atacora, women on their individual or collective farms often grow grain legumes, except groundnut. For example in Matéri, women grow grain legumes on 36% of the farming area whereas only 10% is used for this purpose by men (CARDER Matéri, 2001). These farmlands are mostly handed over by the women's husbands and usually consist of degraded soils. From field observations it became clear that men do the physically hard work such as mounding, ridging and land clearing. Sowing, inorganic fertilizer application in the case of cotton and maize, cow dung and house waste transportation, weeding and harvesting are done by women.

The major problems facing the farming system in the Atacora region as listed by the farmers are the rapid decline of soil fertility, weeds and witch weed (*Striga hermonthica*) infestation, the high cost of inorganic fertilizers (200 F CFA[1] per kg for both NPK-SB and urea), and finally the increasing unpredictability of the rainfall. However, a decreased water-holding capacity of the soil, due to loss of soil organic matter, may have caused the problem of an apparently lower water availability. The farmers in the Savè region mentioned as major constraints market outlet - which has to do with the low prices farmers receive for their produce

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[1] 1000 F CFA = € 1.54

- land tenure (mentioned by the settlers), decrease of soil fertility especially for the *Ilè ignin* soils, and the high cost of inorganic fertilizers.

Farmers' strategies for crop production and soil fertility maintenance

Farmers cope with loss of soil fertility by implementing various practices (Table 2). In total, 11 strategies were identified in the Atacora region while only six were recorded in Savè. In the Atacora region, the strategies most preferred, both by men and women are inorganic fertilizer combined with organic residues, inorganic fertilizer alone, cotton rotated with maize plus inorganic fertilizer (50 kg ha^{-1} of both NPK-SB and urea) applied to the maize, and grain legumes rotated with cereals. Only farmers owing oxen applied cow dung. Because of transportation problems, farmers do not use cattle dung from the herdsmen, who mostly live isolated from the villages. In Savè region, the indigenous farmers and settlers preferred inorganic fertilizer, extensive cassava cropping systems, and crop rotation. Extensive cassava cropping is known in French as 'jachère manioc', literally meaning cassava fallow. Strictly speaking such systems are not considered fallows as crops are still grown, but this rather extensive practice leads to a much slower degradation of the soil. In both regions, the Peulh people have a rotational system that allows a good distribution of animal manure on the fields surrounding the farm-house. Some of the practices are old, *i.e.*, passed on from generation to generation, like natural fallow, the use of household waste, crop rotation and extensive cassava cropping. Other strategies have been introduced by the extension service and are new, like inorganic fertilizer and cotton rotated with maize.

Strategies to maintain soil fertility may not only involve biophysical interventions. If the productivity of the land cannot be sufficiently increased, pressure can be put off the land by migration. Emigration is a strategy used by the younger generation. The older generation generally decides to stay, and applies household waste, animal manure, or a combination of inorganic fertilizer and animal manure or household waste a way of improving soil productivity. Planting egusi melon and incorporating legume residues are strategies used by women. Extensive cropping with cassava or egusi melon, the application of household waste, and ridging/mounding are indigenous strategies. Some of the strategies are area specific. For example, the use of animal manure or household waste is specific to the Atacora region and extensive cropping of egusi melon and cassava is found in the Savè but not in Atacora. However, extensive cassava cropping is also a strategy employed in parts of Ghana (Adjei-Nsiah *et al.*, 2004). The difference between Atacora and the Savè region in terms of strategies concerning animal manure is cultural. The Tchabè people recognize the effectiveness of animal manure but socially they do not want to be confused with the *Peulh* (*Fulani* in the local dialect). Collecting cow dung is seen as useless and culturally non-acceptable. Because the soils in Savè region are

Table 2. Average rankings by male and female farmers of some local soil fertility management practices used in different villages in the Atacora and Savè regions of Benin. Practices listed on the basis of their relative importance in Tchato. For the soil types in the different villages, see Table 1. n = number of farmers who participated in the group discussion.

Soil fertility management practices	Atacora region								Savè region			
	Tchato		Tchanhoun-Cossi		Madjatom		Gnalo		Ouoghi Central		Ouoghi Gare n = 23[1]	Boubouhou n = 25[1]
	Male n=12	Female n = 4	Male n=23	Female n = 18	Male n=15	Female n = 22	Male n=41	Female n = 38	Male n=12	Female n = 4		
Mineral fertilizer	1	2	4	6	2	2	2	3	1	1	1	5
Household waste	2	4	7	8	4	7	7	2	-	-	-	-
Cotton-cereal rotation	3	3	2	4	3	3	4	5	3	2	2	6
Grain legumes/egusi[2]-cereal rotation	4	5	8	2	6	8	9	6	1	2	2	3
Crop residues incorporated	5	7	3	1	7	4	8	7	-	-	-	-
Cereal intercropped with grain legumes	6	6	6	3	5	6	10	4	5	6	-	2
Ridging/mounding	7	1	9	9	9	10	6	8	-	-	-	-
Natural fallow	8	8	5	5	10	9	5	11	6	4	5	4
Emigration	9	9	10	10	11	12	11	9	-	-	-	-
Inorganic fertilizer combined with animal dung	-	-	1	7	1	1	1	1	-	-	-	-
Extensive cassava	-	-	-	-	8	5	3	10	4	5	4	1

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[1] Male farmers only. Because of heavy workload no women appeared during group discussion.

[2] Egusi melon was mentioned in the Savè region only.

more fertile, the migrants from Atacora abandon the use of cow dung.

Farmers from Atacora region believe that climate, especially rainfall, is the most important factor affecting soil fertility management, followed by timely ploughing, weeding and credit. Farmers' access to the extension service (providing information and knowledge) may also improve soil fertility management. On the other hand, the major constraints identified in Savè region were credit, timely weeding and land tenure (mentioned by the settlers).

Land tenure arrangement in the Savè region

The result from the exploratory survey done in the Savè region showed that the percentage migrants in Tchaourou and Savè were 28 and 37, respectively. Most migrants belonged to the following ethnic groups: Ditammari and Yom from Atacora region, Fon from Abomey plateau and Idatcha from Dassa-Zoumè and Glazoué. The migrants, especially the youths - because their fathers are still alive and use the land – after having been confronted with soil degradation leave the village for better living conditions in an area where the soils are more fertile.

Two categories of migrants can be distinguished. The first category comprises those who have settled in the area and who once a year return to their native village to fulfil ritual duties. The second category consists of young people who come temporarily to the region and work as seasonal labourers for the indigenous and for migrants of this first category. After the season they return home with money and purchased goods like motor bike, bicycle and radio / cassette recorder.

In the past there were no strict land tenure arrangements between established migrants and landowners. After one or two years working for an indigenous farmer, the migrants wishing to stay in the village could acquire land from the landowners (represented by the *Bale* literally meaning 'father of the land'). Land is acquired in a traditional way and consists of exchanging gifts and making a contribution to the ceremonies as held by the landowner. In the past a member of the *Bale*'s family did such transactions. A large number of immigrant villages have been established in that way. Nowadays the numbers of immigrant villages is increasing and the land tenure arrangement has changed.

Since 1999, only the 'Comité de Gestion des Terres' in Ouoghi central village, which was created by the village development association (ADESVO), is authorized to arrange contracts with migrants. This committee reports to the village development association including the *Bale* who is also the chief of the village. After the harvest, the migrants pay a substantial rent for land use. Over a period of five years, the rent in Boubouhou had been increased from F CFA 2000 to 10,000 per hectare per year against an increase from F CFA 2000 to 6000 in Ouoghi gare. The rent, which does not depend on the actual yield obtained from the land, has to be paid, otherwise the tenant is evicted from the land. The consequences of this are overuse (to get more profit from the land) and, hence, land degradation. The terms of the contract do not allow the settler to plant trees. Planting trees is seen as a form of land appropriation. Most of the settlers have their farms on the marginal land *ilè ignin* which cannot be cropped for more than four years. When it comes to leave the land fallow, the landowners plant cashew, which prevents the settler to come back on these lands. As a result, most of the migrants of Ouoghi gare have their farms far away (4 – 8 km distance) from the village.

Discussion

Farmer's soil classification versus classification based on soil science criteria

Farmers' criteria for soil classification are more user-oriented and based on the (potential) fertility and on physical properties that affect workability. The most important local criteria for soil classification, as applied by farmers, are based on colour and texture. These criteria are similar to criteria used elsewhere in West, Central and Southern Africa as observed by De Steenhuijsen Piters (1995), Murwira and Mukamuri (1998) and Ishida *et al*. (2001). Soil colour provides qualitative information about content. The darker the soils, the more organic matter they contain and the more fertile they are. Light-coloured (brownish) soils contain less organic matter and are, therefore, less fertile. Such observations made by farmers are in agreement with results of soil chemical analysis. Land evaluation by farmers is not only related to chemical soil fertility but also to soil texture (physical aspects of soil fertility). Farmers define soil texture by the soil's water-holding capacity, which is related to soil organic matter content. Indeed, soil rich in organic matter has higher water-holding capacity, and thus has better textural characteristics. The perception of soil texture by farmers of Atacora and Savè regions is similar.

From this study it has been learned that farmers are well aware of the beneficial effect of earthworms in the management of the agro-ecosystem. The abundance of earthworm casts is used as soil fertility indicator in both regions. In fact, earthworms positively affect soil fertility by maintaining soil structure, by enhancing the soil nitrogen mineralization, and by bringing back to the surface, through their casts, nutrients that would have otherwise leached (Henrot and Brussaard, 1997). Ants and termites may also have a positive effect on soil fertility, but farmers did not mention ants, whereas termites were valued negatively as destroyers of crops.

Farmers' strategies for crop production and soil fertility maintenance

Farmers of both regions have developed and/or inherited complex farming systems that have helped them to meet their subsistence needs. For instance, farming systems in which animal manure is used have allowed the farmers to improve resource use efficiency. Farmers in the Atacora region argue that animal manure combined with inorganic fertilizer is the most effective way of maintaining soil fertility and improving yield. Such a strategy is often called integrated plant nutrient management (Janssen, 1993).

The extensive cassava cropping system, which is claimed by farmers in Savè region as a system that regenerates soil fertility, also has a financial risk minimization function. Harvesting is flexible in time, *i.e.*, roots are harvested when there is a need for cash, leaving the cassava for about 18–24 months in the field. Farmers attribute soil improvement by extensive cassava cropping to the ability of the cassava to form a dense canopy that protects the soil from the impact of the solar radiation and rain. Its high litter production (especially if the litter is rich in N, P or K), when decomposing together with the roots left unharvested, contributes to the regeneration of soil fertility. This phenomenon is not well understood, because conventional science considers that cassava a nutrient-depleting crop (Silvestre, 1987; Sitompul *et al.*, 1992) when harvested after 6-9 months. So it is important to test, together with farmers, the validity of their claim. Such tests should include studies about the role of different cassava cultivars, the magnitude of the effect, and the possible mechanisms involved. Extensive cropping may mean lower nutrient extraction. Cassava rooting patterns and/or mycorrhizal association may lead to enhanced phosphorus-availability, and a favourable microclimate may increases soil biological activity. The system should be part of further scientific investigations to test which cassava landraces have this beneficial effect and on what types of soils.

Like all members of the Cucurbitaceae, creeping egusi melon cultivars grown in the Savè region produce a lot of biomass that covers and protects the soil against the negative effect of solar radiation and runoff. As with extensive cassava cropping, the favourable microclimate may stimulate soil fauna activity, especially of earthworms. If soil moisture is not limiting egusi leaves decompose rapidly and improve soil fertility. The potential role of egusi melon in enhancing soil fertility has never been investigated by conventional science. Further investigations are needed to test which egusi landraces may regenerate soil fertility efficiently. Such research should explicitly include earthworms. Farmers associate the presence of earthworms with fertile soils, while at the same time overlooking a possible causal role of earthworms in the maintenance of soil fertility.

The differences in soil fertility management strategies ranking between the villages and regions are large. This may be due to differences in pressure on farmlands, ethnic differences, cultural differences, differences in soil quality, in rainfall or in agronomic practices. For example, the agro-climatic conditions in the Atacora region do not allow the cultivation of cassava and egusi, and the soils in the Savè region are rather fertile. The difference in soil fertility management strategies between the Atacora and Savè region reflects the differential needs for soil fertility management, the different availabilities of animals especially oxen, resource availability, and tradition. These differences lead to differences in pressure on the land and to different solutions. At a higher level, however, these solutions are interconnected, as emigration from Atacora relieves local pressure but increases pressure on the land in the Savè region. Solutions in Savè through tenure arrangements may lead to different options for migrants, and young migrants come as seasonal labourers from Atacora to Savè, whereas the money earned with their labour flows from Savè to Atacora.

Land tenure arrangements: a prisoner's dilemma?

It is not easy to find a neutral language for describing the effects of land tenure arrangements on soil fertility management. Are landlords 'forcing' the immigrant settlers to mine the soils? Are migrants trying to maximize 'immediate profit' while disregarding long-term sustainability? Or is the increasing monetarization of agriculture leading to a situation that can best be described as prisoner's dilemma, where both parties act rationally in the short run, even if the final outcome is soil degradation? In his article 'The tragedy of the commons' Hardin (1968) highlighted the importance of prisoner's dilemma in land management. Hardin refers to a similar situation, *i.e.*, individuals maximizing their own short-term benefit even at the expense of the long-term common good. However, this tragedy only occurs under a number of assumptions that may not pertain in our case. Hardin's tragedy of the commons' assumes an atomistic society, where all individuals play symmetrical strategies, and where there are no institutions to regulate co-operation and conflict. Under these conditions Hardin's solution, *i.e.*, private property of the land, may be the only solution. In cases where there are institutions like tenure arrangements, even if these institutions are weak or asymmetrical, a larger range of solutions is possible. But it is important to emphasize that adherents of the neo-Boserupian view that increased populations can also improve the fertility of the land, mention the importance of security in tenure arrangements as a necessary conditions (Tiffen and Mortimore, 1994 ; Fairhead and Leach, 1995).

In the Savè region, there is a basic asymmetry because of property rights on the land, so power relations enter the interaction. The best way out of the prisoner's dilemma is through the build-up of mutual trust. So it is important to understand the factors enhance or diminish mutual trust (see Adjei-Nsiah *et al.*, 2004). Both parties are also heterogeneous and each may have a variety of potentially conflicting interests. Seasonal migrants may be different from migrants who finally settle in the village and return only once a year to their original village to participate in the annual rituals. Older landlords with share-cropping arrangements may be different from their younger fellows who prefer financial arrangements. And finally, there is a socio-economic dynamism, where monetarization of agriculture is of increasing importance: changes from subsistence agriculture to cash-crop agriculture, expanding markets due to better transportation facilities, and hence diminished control by producers over prices at local markets.

Both diversity and dynamism affect the space that is available for experimentation among farmers and farmer groups for alternative arrangements. Do land-for-labour transactions (share cropping) enhance mutual trust more efficiently than land-for-money transactions? If so, does the change in arrangements reflect a loss of trust? But is it possible to go back to the older arrangements or are these irretrievably lost? Does people's willingness to engage in novel arrangements weaken their position within their group? Should such agreements therefore be handled collectively on a community platform or should space for negotiation be sought among individual villagers without the risk of group pressure? Game theory suggests that increases in group size reduce the likelihood of making stable arrangements, as failure to comply with the negotiated arrangements could take place both between and within groups. And finally, to what extent is the situation in Savè region context-specific and to what extent are global processes important? Considering similarities between conflicts about tenure arrangements in this study and in the study in Ghana (Adjei-Nsiah *et al*., 2004), this question is relevant as well.

Whereas the diagnostic study itself has not provided answers to these questions, the study did show how much soil fertility issues are embedded in tenure arrangements, and how these are embedded in a village or world of power and trust. The diagnostic study has at least clarified that a rough approach, which attributes 'guilt' to immigrant settlers or landlords and for which a community-wide platform provides the only way out of this dilemma, runs a risk of failure. It is clear that experiments in the social domain of tenure arrangements have to be an important element of the next research phase.

Reflections on the diagnostic study as an entry point for understanding farmers' practices and attitudes towards sustainable soil fertility management

What difference does this diagnostic study make? Does a diagnostic study have to start by assessing all of the village problems or farming constraints while knowing that not all of these could be studied or resolved? This question raises the problem of background knowledge and disciplinary specialization needed for a diagnostic study. However, a diagnostic study should make these implicit considerations explicit. In retrospect, it is clear that the diagnostic study led to changes. Tangible results of this approach were (1) the way villages were selected, (2) the strategies that were adopted to involve farmers in the research process, (3) the interactions between farmers and scientists and the ways farmers challenged us to accept their findings, (4) the agreement that came up for the continuation of the study, and (5) the implications of the results of this diagnostic study to fine-tune the final research proposal. More importantly, the diagnostic study has led to the identification of new research areas that were not taken into account in an earlier phase. Without it we would have missed farmers' knowledge about the importance of earthworm activity and of litter decomposition related to soil fertility regeneration. We would also have overlooked the connections between landowners and settlers, land tenure arrangements and soil fertility management.

Fifteen villages were visited as part of the diagnostic study, but only seven were selected for the in-depth study and three for the continuation of the research programme. Starting with a larger number of villages and subsequently zooming in gave the opportunity to have a wide overview, which may not have occurred had the diagnostic study been carried out in one village only. How representative are the seven villages that were finally selected for the in-depth study? At this stage we can only state that were these villages that showed most interest in the project.

The diagnostic study has led to a framework for an effective interactive research approach (Fig. 1) on soil fertility management. This approach is an alternative to the top-down approach that has often led to failure of introduced soil fertility management innovations. Instead of adopting externally designed technologies, our approach intends to enhance a joint learning process where we learn from the farmers and in return farmers learn from us. Both farmers and researchers have the chance to challenge each other in order to develop innovations that are effective from a technical point of view and that also are socially and culturally acceptable. The research agenda for the subsequent phase of experimentation is then 'negotiated' with the farmers.

The main issue raised in this diagnostic study was how to find a common framework in which farmers' perception converges with theories of conventional science about the extensive cassava and egusi melon cropping systems. In order to test the validity of farmers' claims, we agreed to investigate the potential of extensive egusi melon and cassava crop rotations as a means to restore soil fertility and maintain adequate crop yields. For the joint learning process, we exchanged knowledge about symbiotic relationships between plant and micro-organisms, especially mycorrhizal associations with cassava roots that improve nutrient and water uptake, and rhizobia (nitrogen-fixing bacteria) that form nodules on legume roots. Fresh groundnut roots and fine cassava roots were shown during a group meeting. Specific emphasis was placed on the active root nodules that when severed exhibit a red colour like blood. Farmers were willing (and curious) to have a specific study on mycorrhizal relationships of cassava, which could improve the supply of phosphorus – a major limiting nutrient - to the subsequent maize crop. Furthermore, farmers will become owners of the research findings. Evidently, such an approach is costly in terms of time and requires that the research team stay as close as possible to the farmers' community. This is even more important in view of the need to engage in discussions and experiments with alternative tenure arrangements.

The next step envisioned consists in the design of a community based research committee including farmer innovators. Such a research committee will be based on farmers' free choice implying that farmers interested in the research activities may deliberately join the group. This strategy, which avoids discrimination among villagers, undoubtedly may present some disadvantages with a large group. So farmers will be involved in the research process to achieve a better dissemination of technology. In such a committee the concept of democratization of science can be taken seriously when farmers and researchers engage in research discussions on an equal basis. Such a system using an interactive approach aims to build local capacity. In this research process, knowledge is generated through building on farmers' experiences and through learning by doing. The farmers are moved and move themselves towards the centre of the research process. However, as indicated above, neither the scientists are marginalized in that process.

The participation level (16 - 79 participants as shown in Table 2) in the community meetings, the liveliness of the debate and the way that farmers defended their claims are indicators of their interest in the new approach experimented. This has been facilitated by the way the researcher was introduced in the community by the local extension agent, viz., as student coming to learning from them.

In the specific context of land tenure, we may start with a joint understanding that present arrangements are unfavourable for the settlers and also unfavourable for the original inhabitants, because land resources are degrading. There is a need to explore possibilities of creating new tenure arrangements between landowners and settlers. It is an open question whether such arrangements should be discussed and negotiated among individuals or within community-wide platforms. The critical issues that affect sustainable land resources management must be gathered. Testing alternative tenure arrangements may ultimately be as important as directly testing alternative soil fertility management strategies.

Conclusions

Farmers have insights and adaptive skills that are based on years of experience. This body of knowledge and learning capability has often been accumulated and communicated over generations. In the Atacora and Savè regions of Benin, soil names used by farmers reflect soil colour, texture, coarseness, and hydrological qualities or soil workability. The main purpose of the indigenous soil classification is to indicate farmers the type of soil management required. Mostly, soil fertility evaluation by farmers gave similar results as soil chemical analysis.

Soil degradation is one of the major problems facing farmers in the regions studied. They cope with soil fertility degradation by developing alternative strategies that include the use of organic residues, inorganic fertilizer, crop rotation, and extensive cassava and egusi melon (*Citrullus* spp. and *Lagenaria* spp.) cropping systems. These two cropping systems are not well understood, because conventional science considers that cassava contributes strongly to nutrient depletion while egusi melon has never been object of research. Their contribution in soil fertility regeneration should be part of further scientific investigations, involving all stakeholders in the research process.

Driven by land degradation elsewhere, farmers from Atacora and the southern regions of Benin migrate to Savè region. Landowners charge the migrants rent for land use and as a consequence these migrants do not invest in long-term soil fertility management practices. The study has shown how much soil fertility issues are embedded in tenure arrangements, and how these are embedded in a village or world of power and trust. The establishment of a platform for negotiation among the stakeholders may come up with sustainable land tenure arrangements that take into account the interests of both the landowners and the migrant settlers. It may encourage the migrants to invest in long-term soil fertility management.

Chapter 3

Earthworm activities in extensive cassava and egusi melon cropping systems in the transitional zone of Benin: linking field experiments with farmers’ perceptions

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Chapter 3

Earthworm activities in extensive cassava and egusi melon cropping systems in the transitional zone of Benin: linking field experiments with farmers' perceptions

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Abstract

Farmers' perceptions about earthworm activities were studied in two villages in the transitional zone of Benin. Ouoghi Central is inhabited by Tchabè (Yoruba subgroup) and they usually own land, while Ouoghi Gare is inhabited by migrants from Atacora and the south, who mainly lease land from the original landowners. Two experiments involving farmers in extensive cassava cultivation (varieties odongbo, Bouaké and Ben 86052) and in egusi melon (varieties baa, ugba and Côte d'Ivoire), cowpea and maize cultivation were designed to open a path between farmer interpretations based on signs and scientific explanations of earthworm casting activities. The research furthermore included group discussions (a stakeholder learning-group forum) and a survey where 91 individual farmers were interviewed using an open-ended questionnaire. Almost all farmers were aware of earthworms, named locally *idjèlè* (soil eater). Natives and migrants were equally knowledgeable, but there were significant gender differences in terms of perception on earthworms. The presence of earthworm casts is used by farmers as an indicator for soil health. Farmers interpreted casts to be a kind of vitamin (*ora* / *udja*) indicating good conditions for crop nutrition. Cast deposition was highest (8-15 t ha^{-1}) in the poorest soil (cassava fields) and lowest in the egusi fields (4-7 t ha^{-1}). Within cassava fields casting was significantly higher with variety Ben than with odongbo and Bouaké. No correlation was found between soil chemical properties and cast biomass. Casts showed significantly higher concentrations of total N, available P, and exchangeable K^+, Ca^{2+} and Mg^{2+} than the topsoil. Farmer involvement in the research activity served to increase their interest in the beneficial effects of earthworms in relation to crop and soil fertility management.

Keywords: Earthworm casts; soil fertility

Introduction

Until recently, the ideas of African farmers about soil fertility and crop management have been underestimated by scientists, e.g., with respect to intercropping to minimize risks (Richards, 1985), soil and water conservation to improve crop production (Reij *et al.*, 1996), or the precision and details given by local people when classifying their soils (Birmingham, 2003; Oudwater and Martin, 2003; Saïdou *et al.*, 2004). This knowledge can be considered as mixture of beliefs, superstitions and practical experience (Ortiz *et al.*, 1999). It is not always clear whether local ideas about soil-crop interactions should be regarded as beliefs, and treated interpretatively (much as, say, anthropologists treat witchcraft beliefs) or whether they are to be understood as empirically-based explanatory understandings comparable with accounts offered by science. One approach is to pick and choose, emphasizing the bits of local knowledge compatible with science, and ignoring the rest (or treating it as problematic superstition).

A different recent trend is to find ways of usefully linking interpretative and explanatory approaches. Methodologically, this requires both a sound rendering of local knowledge (what is the knowledge or belief, and how is it distributed within the population?) and a means to link these local ideas to a science-based explanatory framework. The present paper assesses farmer perception about earthworm activity as a factor in soil fertility. We will show that farmers have widespread knowledge of earthworm activity, and that they correctly regard casts as an indicator of soil fertility. By designing analytical interventions involving farmer participation the extent to which this belief fits with science-based explanations can be assessed. Farmer interest is thereby engaged in developing enhanced understanding of phenomena already recognized in local thought. A pathway is opened for farmers to approach soil fertility phenomena as evidence of processes to be managed. Awareness of signs is shifted towards knowledge of mechanisms.

A diagnostic study carried out in the Atacora region and the transitional zones of Benin revealed a range of alternative local practices. Informants claimed that these practices restore soil fertility and enhance crop production (Saïdou *et al.*, 2004). Farmers suggested that extensive cassava (*Manihot esculenta*) or egusi melon (*Citrullus* spp. and *Lagenaria* spp.) in the rotation system improve the soil when it has become degraded. Extensive cassava cropping is known in French as *jachère manioc*, literally cassava fallow. Strictly speaking such systems are not fallows, as crops are still grown for at least 12 – 24 months, but the extensive practice leads to a much slower mining of the soil (Howeler, 1991, 2002). The shrub-like cassava plant – some varieties more than others – produces fairly abundant leaf litter. The crawling cultivars of egusi melon produce a high vegetative biomass that covers the soil. Farmers argue that under extensive cassava and egusi melon, soils are better protected against solar radiation. As a consequence, these soils have a lower soil temperature and higher retention of soil moisture.

Both factors tend to promote the build up of earthworm populations. However, it is not clear that farmers see this connection. Farmers perceive earthworms as an indicator of soil fertility, not as organisms creating or maintaining soil fertility (Ortiz *et al.,* 1999).

We are faced with a challenge to stimulate local thought to develop a more processual account of the phenomena in question. A starting point is to address a controversy between farmers and scientists. There is apparently a discrepancy between formal research, which has sometimes claimed that cassava depletes the soil (Silvestre, 1987; IITA, 1990; Sitompul *et al.*, 1992), and farmers' notions that extensive cassava cropping can maintain or restore soil fertility (Hinvi, 1990; Saïdou *et al.*, 2004; Adjei-Nsiah *et al.*, 2004). This discrepancy offers a focus around which we might expect to engage both the interest of farmers and scientists. Here we describe work linking farmers' perceptions about cassava and egusi melon and soil fertility to analysis of the potential causal roles of earthworms (casting activity, cast and topsoil nutrient concentration, and amounts of nutrients deposited in surface casts). The study is based on the following four objectives: (1) to understand farmers' beliefs and perceptions (cultural acceptance) of earthworms, (2) to relate these beliefs and perceptions to scientific explanation, (3) to set up joint experiments to serve as a way of linking both forms of knowledge, and (4) to use farmer engagement with the results of the field experiments as a route to develop their own improved soil and crop management practices.

We hypothesized that: (1) different social groups of farmers (migrants versus natives, men versus women, older versus young men) might differ in their knowledge of beneficial effects of earthworms in the different cropping systems; (2) earthworm activity assessed through surface cast deposition would be higher in more fertile soils and under crop cultivars of cassava and egusi melon that better protect the soil; (3) the relative importance of earthworm casts will be larger in less fertile soils.

Materials and Methods

Study sites

The study was carried out in farmers' fields at Ouoghi Central and Ouoghi Gare villages (3 km distant from each other) in the transitional agro-ecological zone of Benin. Ouoghi Central is inhabited by indigenous Tchabè people (Yoruba subgroup) and Ouoghi Gare (a settlement located along a north-south railway line) by migrants from Atacora-Donga and Abomey plateau (Saïdou *et al.*, 2004, 2006). The area is located around 8°07'N and 2°33'E at an altitude of about 200 m a.s.l. The area has a Guinea-Sudan climate with a unimodal rainfall pattern. The average yearly rainfall and temperature are 1100 mm and 27.5°C, respectively. Rainfall at the site lasts from April to mid-November.

The soil is essentially dominated by tropical ferruginous soils (Dubroeucq, 1977) from Precambrian crystalline rocks (granite and gneiss), classified as Ferric Lixisol (FAO, 1990). The surface (0 - 20 cm) soil properties of the egusi melon experimental site at the beginning of the study are: pH($CaCl_2$) (4.9); total N (0.5 g/kg); P-Bray 1 (14.5 mg/kg); exchangeable K^+ (0.23 cmol/kg); 2% clay, 7% silt and 87% sand which leads to a sandy texture. Those of extensive cassava fields ranged: pH($CaCl_2$) (5.6-5.8); total N (0.7-0.9 g/kg); P-Bray 1 (10.6-19.1 mg/kg); exchangeable K^+ (0.18-0.22 cmol/kg); 5-8% clay, 5-6% silt and 86-90% sand which lead also to a sandy texture.

Survey approach

Farmers were full participants in the research rather than an object of study. After a diagnostic study (Saïdou et al., 2004), stakeholder learning groups of respectively 31 and 10 members in Ouoghi Central and Ouoghi Gare were formed on a voluntary basis in February 2003. The group was built on the existing cotton producer group (Groupement des Producteurs de Coton, GPC) and the group was composed by youth and elders and the local extension agent playing the role of facilitator. It was difficult to involve the women because they felt uncomfortable to be in the same group with the men and also because of heavy workload. These stakeholder learning groups served as a forum for interaction and knowledge exchange between farmers and between farmers and researchers. Tools used for knowledge exchange included photos, graphs and descriptions of biological processes (nutrient cycling through earthworm casts) in ecosystems. The purpose of forming such a group was to build farmers' capacity and strengthen their self-confidence. The groups were also important because they were treated as client stakeholder groups for better or more relevant agro-scientific research.

In November 2003, a formal survey with individual farmers was carried out using an open-ended questionnaire including ranking exercises. In order to see whether the group to which respondents belonged affected perceptions and beliefs, responses from natives and migrants, males and females, and older and younger male farmers were treated separately. In total, 91 persons (51 natives and 40 migrants) were interviewed. They were selected with the help of the local extension agent. As with the stakeholder learning groups, farmers' perceptions of the role of earthworms, surface cast abundance and weight in the fields, and factors underlying their abundance were assessed. Farmers were asked to rank different crops with regard to earthworm abundance. Criteria used by farmers were mainly based on the ability of the different canopy crops to cover the soil, to create shade and to conserve soil moisture.

A feedback session between the learning groups and villagers was organized in February 2004 when data were assessed and analyzed. This interactive section with farmers aimed to link traditional knowledge/beliefs concerning earthworms with the results of the field experiment, and to provide possible explanations for divergence in perception/beliefs and field results.

Field experiment

An experiment was set up in order to link farmers' perceptions on earthworms with field results. Earthworm activity was assessed by measuring surface cast production. We did not identify earthworm species. Cassava fields were selected together with the stakeholder learning group members in February 2003 after an exploratory tour in both villages. The main selection criteria were: farmers' attendance at the stakeholders learning group meetings, preparedness of each farmer not only to make a small portion of the field available for the establishment of the on-farm experiment but also to manage the farms as necessary and to participate in data collection, similarity of the land (texture and color), and the cultivars grown.

The cassava system is multi-annual. In the area, cassava is grown by native and migrant farmers at the end of the rotation in order to allow the soil to regenerate its original fertility. Three cassava cultivars are grown in the area: odongbo (a local landrace), Bouaké (a fast growing cultivar introduced from Côte d'Ivoire), and Ben 86052 (an improved and high yielding cultivar introduced by researchers). Ben 86052 has a dense canopy (the mean value of canopy diameter is 1.2 m in July when the maximum rainfall is registered), while Bouaké and odongbo have a rather open canopy (the mean value of canopy diameter is 0.7 m for both cultivars in July). Ben 86052 was introduced in the area by a cassava project funded by the Benin government. This project aimed to increase cassava production at farmer level by introducing high yielding cultivars, to improve cassava yield in farmer's condition, to improve the quality of cassava products, to satisfy the national and international demands for cassava products, and finally, to alleviate poverty (MAEP, 1999). The project recommended to farmers to apply mineral fertilizer (100 kg urea ha^{-1} urea, 100 kg triple superphosphate ha^{-1} and 200 kg potassium sulfate ha^{-1}) in order to sustain the production and to counterbalance the negative nutrient budget. The introduction of this new landrace did not take sufficiently into account whether it fitted local conditions and/or was acceptable to farmers.

The experiment was set up in a completely randomized block design with cassava cultivars as treatments. For each cassava cultivar, six farmers (three natives, three migrants) were selected. There were three replicates per farmer. Cassava fields were 6-18 months old. In each farmer's field, plots of 30 m^2 (6 m x 5 m) were delimited in the center to avoid edge effects.

The egusi melon system is annual. It is sown soon after the first rains. It has a cropping cycle of 3 to 4 months. The leaves cover the soil 2 months after sowing. The preceding crops cultivated are maize, sorghum, cotton or grain legumes and the subsequent crops are maize, cassava or sorghum. The experiment was carried out according to a completely randomized block design with four replications and five treatments consisting of three egusi melon species and two further crops: *Citrullus colocynthis* (egusi baa), *C. lanatus* (egusi Côte d'Ivoire), *Lagenaria siceraria* (egusi ugba), *Vigna unguiculata* (cowpea cultivar Tawa) and *Zea mays* (maize cultivar TZB). The maize field was used for comparative purposes, while cowpea was used because by fixing atmospheric nitrogen it improves soil fertility, which could affect earthworm activity. Farmers suggested to include cowpea and maize in the design as part of the local crop management practices but the main concern here was the egusi melon fields. The experiment started in April 2003 when egusi baa, egusi Côte d'Ivoire and cowpea were sown at a density of 62,500 plants ha^{-1} and egusi ugba and maize at 25,000 plants ha^{-1}. The large difference in planting densities between egusi melon cultivars is mainly based on plant physiology. Farmers stated that when egusi ugba, which has much bigger fruits than the other egusi melons, is planted close together, it negatively affects yield.

Measurement of earthworm surface casting

The standing mass of earthworm granular (more common) and tubular casts that had accumulated at the soil surface was counted and collected in four sub-plots of 0.25 m^2 (0.5 m x 0.5 m) delimited randomly in each plot of 30 m^2 of cassava or egusi melon. The production rate of casts was estimated from 02 June to 28 October and 09 June to 24 July for the cassava and egusi melon experiment, respectively. All surface casts were collected and counted from each sub-plot every two weeks. Casts were dried firstly at ambient air and then at 40^{o}C to a constant weight in an electric oven in the laboratory. The dry casts were sieved through a 2 mm sieve in order to remove plant material and stones and weighed. Cast material was pooled per plot at the end of each sampling period for chemical analysis. From 15 July to 15 August the cassava fields were disturbed by weeding.

Nutrient concentrations of casts were compared with those of the underlying topsoil (0-10 cm depth) at the end of the rainy season (November) for cassava and at the end of the cropping cycle (August) for egusi melon. Chemical analyses were performed in the Laboratory of Soil Sciences of the Faculté des Sciences Agronomiques of the University of Abomey Calavi and at the Laboratoire des Sciences du Sol, Eau et Environnement of Benin National Research Institute (LSSE/INRAB). Soil and casts were analyzed for pH($CaCl_2$) (1:2.5 v/v soil solution), total N (Kjeldahl digestion in a mixture of H_2SO_4-selenium followed by distillation and titration), available P (Bray 1), exchangeable cations (with 1 N ammonium acetate at pH 7; then, K was determined by flame photometer, and Ca and Mg by Atomic Absorption Spectrophotometry).

Statistical analysis

Data were analyzed in SAS v 8.1. Soil and cast chemical properties and amount of nutrients deposited were subjected to analysis of variance and means were compared using Student

Newman-Keuls test. The number of casts per unit of surface and cumulative cast mass were ln transformed to satisfy the conditions of normal distribution of data before analysis. Nutrient enrichment in casts as a function of soil properties was calculated. Differences between the distribution of responses were determined by the Chi-square test after grouping similar responses. Because informants were limited to give only one answer, the answers given reflect farmers' conceptions of the most important role (and not the variety of roles) that earthworms play. Minitab 13 software was used to complete the analysis.

Results

Farmers' perception and knowledge on earthworms and factors underlying casting activity

Almost all farmers were knowledgeable about earthworms. They are locally named *idjèlè* (which literally means soil eater). Earthworm casts are considered as vitamin (*ora* or *udja*) *i.e.* fertilizer because they are richer than the topsoil. The farmers considered surface casts as a soil fertility indicator (Table 1). Several farmers reported the importance of earthworms in litter decomposition. A few other farmers perceived earthworms as source of human foot infection and / or as root herbivores. The perceptions of the farmers of the role of earthworms are summarized into three categories: (1) positive (soil fertility indicator or improver, litter decomposer and plant residues burrower), (2) negative (crop roots feeder and source of infection) and (3) indifferent (no opinion). Natives and migrants did not have different ($P = 0.23$) perceptions or beliefs on the role of earthworms. Gender differences in perception were significant ($P = 0.01$). Female farmers appeared to be less knowledgeable on the role of earthworms than male farmers. Elder and younger males had similar ($P = 0.45$) perceptions on the role of earthworms.

Table 2 presents the ranking made by farmers on the intensity of earthworm casting activity in cassava, egusi melon, cowpea and maize fields. Most natives (except young males) reported that earthworm activity was highest in cassava fields, while migrants mentioned intense casting activity in egusi melon fields. Both native and migrant groups mentioned lowest casting activity in maize fields.

Table 1. (a) Relative distribution (%) according to the social groups of farmers' responses on the role of earthworms and (b) Chi-square test determining the level of significance by grouping farmers' responses. (Symbols for significance levels: $^{**}P < 0.01$, ns not significant).

(a) Role of earthworm	Natives			Migrants			Total[3]	
	Older[2] (n = 18[1])	Young (n = 20)	Women (n = 13)	Older (n = 14)	Young (n = 16)	Women (n = 10)	Men (n = 68)	Women (n = 23)
Soil health improvement (Positive effect)								
Soil fertility indicator	28	60	23	57	44	30	47	26
Contribute to litter decomposition	17	10	8	7	6	10	10	9
Bury plant residues	11	5	0	7	12	0	9	0
(Negative effect)								
Crop roots herbivores	11	5	8	14	25	20	13	13
Cause infection	6	10	15	7	6	10	16	13
No opinion	28	10	46	7	6	30	13	39

(b) Level[4] of significance determined by Chi-square test	Chi-square	*P*-level
Natives vs migrants	2.941 ns	0.230
Olders vs young males	1.612 ns	0.447
Men vs women	8.971^{**}	0.011

[1] n = Number of respondents

[2] People of 50 years old upward are ranged within the group of older, otherwise ranged in the group of young

[3] Total for men is the sum of responses of older and young belong to natives and migrants groups and total for women is the sum of responses of natives and migrants women

[4] Level of significance tested by grouping farmers' responses into: (1) soil health improvement (soil fertility indicator, contribution to litter decomposition, bury plant residues), (2) negative effect (destroy crop roots, Cause infection), and (3) no opinion

Table 2. Ranking order of the intensity of earthworm casting activity according to different farmers' social groups in different cropping systems. Casting activity ranked based on the relative importance as perceived the older of the natives groups. 1 = Highest and 4 = lowest

Fields	Natives			Migrants		
	Older (n = 18[1])	Young (n = 20)	Women (n = 13)	Older (n = 14)	Young (n = 16)	Women (n = 10)
Cassava	1	3	1	2	2	2
Egusi melon	2	1	2	1	1	1
Cowpea	3	2	2	3	3	2
Maize	4	4	4	4	4	4

1) n = Number of respondents

The majority of migrants and natives perceived rainfall or soil moisture as the main factor underlying earthworm casting activity (Table 3). High soil fertility status and litter abundance were other less important factors listed. Some farmers attributed casting activity to divinity. Only a few farmers (mainly women) gave no opinion. The different factors underlying casting activity listed by the farmers were grouped as: (1) ecological factors (rainfall/soil humidity, soil fertility and litter abundance) and (2) divinity (spiritual factors). This second grouping contains answers that amount strictly to having no opinion; this is because in common with many parts of rural Africa, inexplicable phenomena are assigned to the realm of divine causality. Based on this grouping, a Chi-square test showed no significant differences in beliefs/perceptions between natives and migrants ($P = 0.21$) on the factors underlying earthworm casting activity. Gender differences in perception were moderately significant ($P = 0.1$). There was also a moderately significant difference ($P = 0.09$) between older and younger males in perceptions or beliefs concerning factors underlying earthworm casting activity.

Earthworm surface cast biomass and distribution

The earthworm casts in the cassava, egusi melon, cowpea and maize fields comprised two distinct types: small granular and tubular. The granular casts were abundant and found in all fields whereas no more than two tubular casts were counted per field during each period of measurement. For that reason, the latter have been mixed with the granular casts.

The average number of casts per square meter and the total cast mass in the various fields are presented in Table 4. The average and total number of casts and cast mass in the Ben and Bouaké fields were significantly ($P < 0.05$) higher than in the odongbo fields. Cast abundance and cast mass were significantly ($r = 0.638$ and 0.518 respectively, $n = 18$; $P = 0.004$ and 0.028)

Table 3. (a) Relative distribution (%) according to the social groups of farmers' responses on factors underlying earthworm casting activity and (b) Chi-square test determining the level of significance by grouping farmers' responses. (Symbols for significance levels: † $P < 0.1$, ns not significant).

(a) Factors promoting earthworm abundance	Natives			Migrants			Total[3)]	
	Older[2)] (n = 18[1)])	Young (n = 20)	Women (n = 13)	Older (n = 14)	Young (n = 16)	Women (n = 10)	Men (n = 68)	Women (n = 23)
Ecological factors								
Soil fertility status	6	5	8	21	19	20	12	13
Rainfall/soil moisture	67	75	54	50	69	50	66	52
Food/litter abundance	6	10	8	14	12	10	10	9
Divinity								
Spiritual factor/God	22	0	15	7	0	10	7	13
No opinion	0	10	15	7	0	10	4	13

(b) Level[4)] of significance determined by Chi-square test	Chi-square	*P*-level
Natives vs migrants	1.59 ns	0.21
Olders vs young males	2.841†	0.09
Men vs women	2.708†	0.1

[1)] n = Number of respondents

[2)] People of 50 years old upward are ranged within the group of older, otherwise ranged in the group of young

[3)] Total for men is the sum of responses of older and young belong to natives and migrants groups and total for women is the sum of responses of natives and migrants women

[4)] Level of significance tested by grouping farmers' responses into: (1) ecological factors (inherent soil fertility, soil moisture/rainfall, food/litter abundance) and (2) divinity (spiritual factors, no opinion) correlated with cassava canopy cover. In the second experiment, the lowest numbers and mass of casts were observed in egusi baa fields and the highest in maize and cowpea fields (Table 4). The following ranking order for cast mass was found: cassava > maize > cowpea > egusi melon. Native farmers ranked cassava highest, and the migrants ranked egusi highest. In general, the farmer ranking order did not fully reflect the results of field experiment.

Table 4. Mean values (± standard error) of earthworm casts number per square meter and cast weight (t ha^{-1}) from June-July in the extensive cassava, egusi melon, cowpea and maize fields and from August-October in the extensive cassava fields. The values were ln(n+1) transformed before analysis of variance. Figures in parentheses are the original values. In a column, means followed by the same letter are not significantly different ($P > 0.05$) (Newman-Keuls test). (Symbols for significance levels: * $P < 0.05$, ** $P < 0.01$, ns not significant).

Fields	June-July		August-October		Overall mean number	Cumulative weight
	Number	Weight	Number	Weight		
(a) Cassava						
Odongbo	1.6 ± 0.07 b	0.7 ± 0.08	1.7 ± 0.07 b	0.7 ± 0.08 b	1.7 ± 0.06 b	0.9 ± 0.08 b
	(38.6)	(3.8)	(57.6)	(4.0)	(48.1)	(7.8)
Bouaké	1.9 ± 0.08 a	0.8 ± 0.05	2.0 ± 0.05 a	0.8 ± 0.02 a	1.9 ± 0.06 a	1.1 ± 0.03 a
	(78.4)	(5.9)	(95.6)	(5.5)	(87.0)	(11.4)
Ben 86052	2.0 ± 0.14 a	0.9 ± 0.1	2.0 ± 0.05 a	0.9 ± 0.08 a	2.0 ± 0.09 a	1.2 ± 0.07 a
	(126.8)	(8.3)	(99.4)	(6.7)	(113.1)	(15.0)
$P > F$	0.04^{*}	0.14 ns	0.01^{**}	0.05^{*}	0.02^{*}	0.02^{*}
(b) Egusi-cowpea-maize						
Baa	1.6 ± 0.05	0.7 ± 0.03 b				
	(44.5)	(4.2)				
Côte d'Ivoire	1.8 ± 0.08	0.9 ± 0.05 ab				
	(63.2)	(6.7)				
Ugba	1.8 ± 0.07	0.8 ±0.01 ab				
	(61.6)	(5.9)				
Maize	2.0 ± 0.08	1.1 ± 0.05 a				
	(93.5)	(10.5)				
Cowpea	1.8 ± 0.2	1.0 ± 0.1 a				
	(74.8)	(8.5)				
$P > F$	0.26 ns	0.01^{**}				

Earthworm cast and topsoil chemical properties

Earthworm casts pH($CaCl_2$) and nutrient concentrations were significantly ($P < 0.001$) higher than those from the underlying topsoil (Table 5). In the cassava fields, cast : topsoil ratios were 1.3-2.4 for total N, 1.5-2.5 for exchangeable K^+, 1.6-2.9 for Ca^{2+}, and 1.9-2.4 for Mg^{2+} (Table 6a). In the egusi-cowpea-maize experiment, the cast : topsoil ratios were also increased. In the cowpea field cast : topsoil ratios for total N and exchangeable K^+ were higher than in the egusi and maize fields (Table 6b). The underlying topsoil chemical properties were not significantly correlated with cast mass.

Table 5. Three way ANOVA (F-values) of earthworm cast and topsoil pH and nutrient concentration regarding (a) source of material (component), cassava cultivar and farmers variability and (b) source of material (component), field types, and blocs. (Symbols for significance levels: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; ns not significant).

Sources of variation	df	F-values					
		pH_{CaCl2}	Total N	P-Bray1	Exch. K	Exch. Ca	Exch. Mg
(a) Cassava							
Component[1)]	1	49.41^{***}	33.50^{***}	3.42 ns	50.93^{***}	49.71^{***}	185.37^{***}
Cultivars	2	5.44^{*}	4.97^{**}	8.66^{*}	3.78 ns	0.09 ns	0.40 ns
Farmers variability	5	1.54 ns	1.22 ns	2.10 ns	2.26 ns	1.00 ns	2.98 ns
Farmers*cultivars	10	1.37 ns	2.34 ns	2.84 ns	3.48^{*}	1.80 ns	8.72^{**}
Farmers*component	5	0.21 ns	0.83 ns	0.84 ns	0.97 ns	2.00 ns	2.74 ns
Cultivars*component	2	7.14^{*}	4.67^{*}	5.22^{*}	1.04 ns	2.27 ns	1.32 ns
CV (%)		3.3	28.4	25.5	23.7	28.4	14.6
(b) Egusi-cowpea-maize							
Component[1)]	1	93.01^{***}	7.57^{*}	12.31^{***}	20.78^{***}	88.96^{***}	40.40^{***}
Treatments	4	12.89^{***}	3.62^{*}	0.94 ns	3.04 ns	8.68^{***}	1.34 ns
Blocs	3	4.01^{*}	2.08 ns	4.87^{*}	2.71 ns	2.80 ns	1.40 ns
Blocs*treatments	12	3.15^{*}	1.53 ns	3.27^{*}	0.67 ns	3.16^{*}	1.50 ns
Blocs*component	3	0.96 ns	1.27 ns	4.17^{*}	0.19 ns	0.77 ns	0.11 ns
Treatments*component	4	3.26 ns	2.11 ns	4.38^{*}	1.08 ns	0.57 ns	0.32 ns
CV (%)		3.13	38.1	15.4	43.5	14.4	29.5

[1)] Topsoil versus cast

Table 6. Mean values (± standard errors) of topsoil (0-10 cm depth) and earthworm cast chemical properties in (a) extensive cassava fields and (b) cowpea, maize and egusi fields. In a column, means followed by the same letter are not significantly different ($P > 0.05$) (Newman-Keuls test). (Symbols for significance levels: $^{\dagger}P < 0.1$, $^{*}P < 0.05$; $^{**}P < 0.01$; ns not significant).

Fields	pH($CaCl_2$)		Total N (g kg^{-1})		P-Bray 1 (mg kg^{-1})		Exchangeable K^+ (cmol kg^{-1})		Exchangeable Ca^{2+} (cmol kg^{-1})		Exchangeable Mg^{2+} (cmol kg^{-1})	
	Soil	Casts	Soil	Casts	Soil	Casts	Soil	Casts	Soil	Casts	Soil	Casts
(a) Cassava												
Odongbo	5.2 ± 0.1	5.9 ± 0.1 a	1.0 ± 0.1	1.7 ± 0.1 a	27.7 ± 2.2 a	29.3 ± 4.3	0.4 ± 0.04	0.6 ± 0.1	1.1 ± 0.2	1.9 ± 0.2	1.0 ± 0.1	1.8 ± 0.2
Bouaké	5.4 ± 0.1	5.9 ± 0.1 a	0.8 ± 0.2	1.0 ± 0.1 b	15.5 ± 3.3 b	27.7 ± 2.4	0.2 ± 0.1	0.5 ± 0.1	1.1 ± 0.2	1.8 ± 0.3	0.8 ± 0.1	1.9 ± 0.2
Ben 86052	5.3 ± 0.1	5.5 ± 0.1 b	0.7 ± 0.1	1.7 ± 0.2 a	20.3 ± 3.1 ab	17.4 ± 3.4	0.3 ± 0.1	0.6 ± 0.1	0.8 ± 0.1	2.2 ± 0.2	1.0 ± 0.2	1.9 ± 0.1
P > F	0.38 ns	0.002^{**}	0.61 ns	0.02^{*}	0.04^{*}	$0.09^{\dagger}$	0.11ns	0.75 ns	0.42 ns	0.48 ns	0.78 ns	0.93 ns
(b) Egusi-Cowpea												
Egusi baa	5.1 ± 0.2	5.9 ± 0.1 a	1.1 ± 0.2	1.1 ± 0.1	26.8 ± 3.9	22.6 ± 4.4	0.3 ± 0.1	0.6 ± 0.03	0.8 ± 0.1 ab	1.1 ± 0.03	0.7 ± 0.03	1.1 ± 0.1
Egusi ugba	4.8 ± 0.1	5.3 ± 0.2 b	1.0 ± 0.1	1.2 ± 0.1	21.9 ± 2.1	32.0 ± 1.8	0.3 ± 0.04	0.4 ± 0.1	0.6 ± 0.1 b	0.9 ± 0.1	0.5 ± 0.1	0.9 ± 0.1
Egusi Côte d'Ivoire	5.3 ± 0.1	5.8 ± 0.1 a	1.4 ± 0.4	1.8 ± 0.3	22.2 ± 2.8	31.4 ± 1.7	0.3 ± 0.1	0.6 ± 0.1	0.7 ± 0.03 b	1.1 ± 0.1	0.6 ± 0.1	1.2 ± 0.1
Maize	5.2 ± 0.1	5.5 ± 0.2 ab	1.2 ± 0.1	1.5 ± 0.1	23.9 ± 3.4	28.9 ± 1.1	0.3 ± 0.1	0.5 ± 0.04	0.7 ± 0.1 b	1.1 ± 0.2	0.6 ± 0.1	1.1 ± 0.2
Cowpea	5.1 ± 0.1	5.6 ± 0.1 ab	1.2 ± 0.1	2.6 ± 0.8	22.9 ± 3.8	24.9 ± 4.9	0.4 ± 0.02	0.9 ± 0.2	0.9 ± 0.1 a	1.3 ± 0.1	0.7 ± 0.2	1.2 ± 0.2
P > F	$0.06^{\dagger}$	0.02^{*}	0.67 ns	$0.07^{\dagger}$	0.77 ns	0.14 ns	0.29 ns	$0.08^{\dagger}$	0.01^{**}	0.23 ns	0.48 ns	0.67 ns

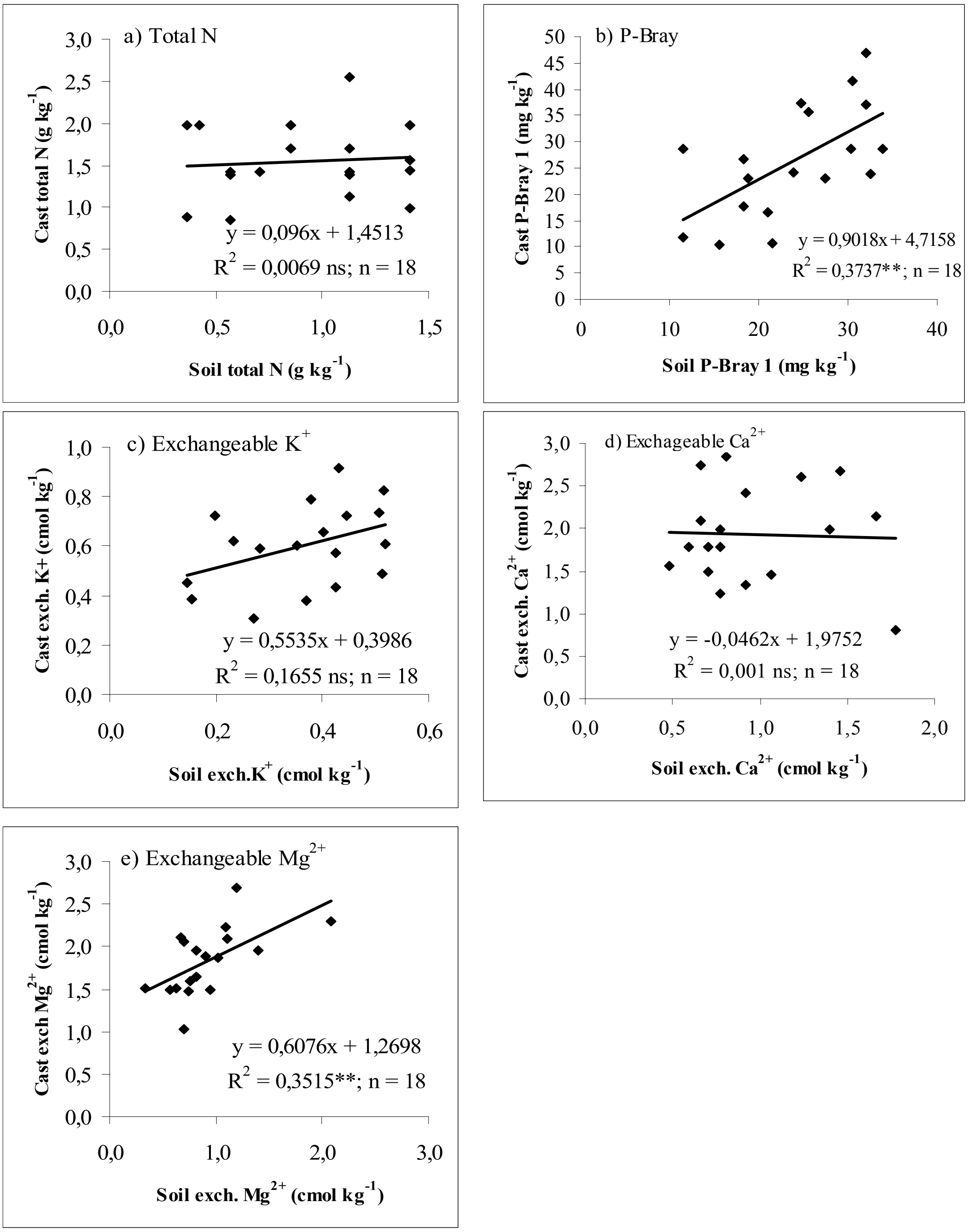

Figure 1 . Relationships between cast and soil concentration (cast enrichment) for (a) total N, (b) P-Bray 1, (c) exchangeable K^+, (d) exchangeable Ca^{2+}, and (e) exchangeable Mg^{2+}. Mean of cassava cultivars odongbo, Bouaké and Ben 86052. ** $P < 0.01$, ns not significant.

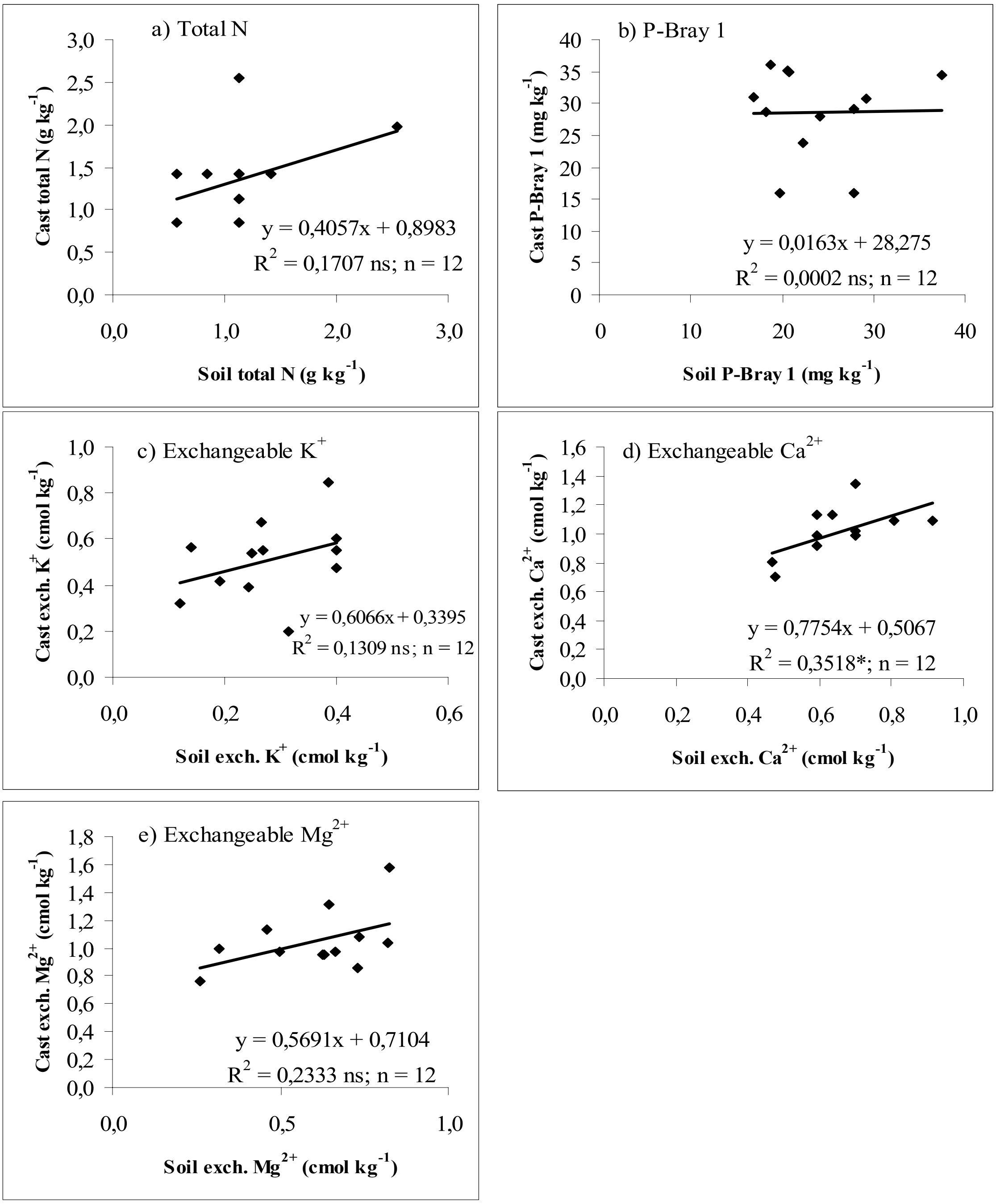

Figure 2. Relationships between cast and soil concentration (cast enrichment) for (a) total N, (b) P-Bray 1, (c) exchangeable K$^+$, (d) exchangeable Ca^{2+}, and (e) exchangeable Ca^{2+}. Mean of egusi *baa*, egusi *ugba* and egusi Côte d'Ivoire. * $P < 0.05$, ns not significant.

Fig. 1 and 2 show cast enrichment as a function of soil properties. In the cassava fields (Fig. 1a-e), cast enrichment with total N and Ca^{2+} was highest in the fields with the lowest fertility. Available P and exchangeable Mg^{2+} content of the casts scaled linearly with available P and exchangeable Mg^{2+} in the topsoil, indicating no specific enrichment in the casts as a function of soil fertility. Exchangeable K^+ showed an intermediate behavior. However, in the second experiment (Fig. 2a-e) cast enrichment in the egusi field was highest for available P while no cast enrichment was registered for exchangeable Ca^{2+}. Total N, exchangeable K^+ and exchangeable Mg^{2+} showed intermediate behavior. There were significant differences ($P < 0.05$) in cast pH($CaCl_2$) between the Ben and Bouaké and odongbo fields (Table 6a). Total N in casts was significantly higher in the Ben and odongbo fields. There were no significant differences between the cassava fields in P-Bray 1, exchangeable K^+, Ca^{2+} and Mg^{2+} concentration in the casts. pH values in the egusi baa and egusi Côte d'Ivoire fields were significantly ($P < 0.05$) higher than in the egusi ugba field (Table 6b). Total N and exchangeable K^+ in the casts from the cowpea fields were 50-100% higher than in the casts from the egusi and maize field, although the difference was not significant.

Amount of nutrients deposited in the casts

In the Ben fields, significantly ($P < 0.05$) higher total N, exchangeable Ca^{2+} and Mg^{2+} were recycled through the casts compared with the odongbo and Bouaké fields (Table 7a). No significant difference between the fields was registered for P-Bray 1 and exchangeable K^+. In the second experiment (Table 7b), the amount of total N and exchangeable K^+ recycled through casts in the cowpea fields were higher than those in egusi melon and maize fields. Most P was recycled through casts in maize fields. There were no significant differences between the fields in the amount of exchangeable Ca^{2+} and Mg^{2+} recycled.

Discussion

Farmers' perception on earthworm casting activity

Farmers' perceptions and knowledge about earthworms and their casting activity was dependent on gender, but not on the distinction between natives and migrants (Table 1). Most farmers considered an abundance of casts as an indicator for fertile soils. Birang *et al.* (2003a) reported similar perceptions with farmers in southern Cameroon, who on the basis of presence of earthworm casts determine if the land is ready for cropping. Beneficial effects of earthworm as mentioned by farmers in our study area were also reported by Ortiz *et al.* (1999) in a survey conducted in Congo, India, Peru and Mexico. In southern Cameroon, Birang *et al.* (2003a) reported that high levels of surface casting were associated with a strong belief in positive yield effects from earthworms. Like in our study area, Birang *et al.* (2003a) reported that some Cameroonian farmers believed that earthworms cause crop damage. Because earthworms live off dead plant parts, consuming dying or dead plants may suggest that they are responsible for the death of the plant. Ortiz *et al.* (1999) also reported that some Mexican farmers considered earthworms to be harmful.

Table 7. Mean values (± standard errors) of the amounts of nutrients deposited in surface casts in (a) extensive cassava and (b) cowpea, maize and egusi melon fields (kg ha^{-1}). In a column, means followed by the same letter are not significantly different ($P > 0.05$) (Newman-Keuls test). (Symbols for significance levels: † $P < 0.1$; * $P < 0.05$; ** $P < 0.01$; ns not significant).

Fields	Total N	Available P	K^+	Ca^{2+}	Mg^{2+}
(a) Cassava					
Odongbo	13.3 ± 2.7 b	0.2 ± 0.1	1.7 ± 0.3	5.4 ± 0.8 b	3.1 ± 0.5 b
Bouaké	13.2 ± 1.2 b	0.4 ± 0.1	2.5 ± 0.4	7.8 ± 1.2 ab	5.1 ± 0.6 ab
Ben 86052	25.0 ± 4.0 a	0.3 ± 0.1	3.6 ± 0.7	13.0 ± 2.9 a	6.4 ± 0.8 a
$P > F$	0.03^{*}	0.34 ns	$0.08^{\dagger}$	0.03^{*}	0.02^{*}
(b) Egusi-cowpea					
Baa	4.5 ± 0.7 b	0.1 ± 0.0 b	1.0 ± 0.1 c	1.8 ± 0.2	1.1 ± 0.2
Ugba	7.1 ± 0.7 ab	0.2 ± 0.0 ab	0.9 ± 0.1 c	2.0 ± 0.1	1.4 ± 0.1
Côte d'Ivoire	11.9 ± 1.5 ab	0.2 ± 0.0 ab	1.5 ± 0.4 bc	3.0 ± 0.6	2.0 ± 0.5
Maize	15.9 ± 3.0 ab	0.3 ± 0.0 a	1.9 ± 0.3 ab	4.8 ± 1.4	3.1 ± 1.0
Cowpea	17.6 ± 5.8 a	0.2 ± 0.1 ab	2.4 ± 0.1 a	4.4 ± 1.0	2.6 ± 0.5
$P > F$	0.048^{*}	0.011^{*}	0.001^{**}	0.11 ns	0.21 ns

The ecological factors identified by the farmers in this study (Table 3) comprised extrinsic factors (not influenced by farmers, such as rainfall) and intrinsic factors (influenced by farmers). The intrinsic factors are directly (food quality) or indirectly (shade, moisture) affecting earthworms. There was a tendency for natives and migrants to look differently at extrinsic and intrinsic factors. Migrants mentioned soil fertility status more often than natives in explaining differences in earthworm activity. A possible explanation is that natives have more fertile and more productive soils than the soils used by migrants (so there is less stimulus to explanatory inquiry). In fact, in the area, natives rent land to the migrant farmers and only less productive lands are rented (Saïdou *et al.*, 2006). Divine action in explaining earthworm casting activity was more often mentioned by elder than by younger males. This is perhaps to be accounted for in terms of young farmers generally having more education, and more exposure to explanatory reasoning, but perhaps also that the young (like migrants) have the less good land, so need to be more explicit about reasons for fertility. As noted above, divine action is tantamount to having – or needing - no other explanation. Natives and migrants generally shared their perceptions on earthworm activities in the various cropping systems. This similarity is probably also due to the nearness of the two villages, because interaction between both groups induces common habits and experiences (Saïdou *et al.,* 2006).

Field experiments

Significant differences were found between the cumulative cast biomasses in the Ben compared to the odongbo fields. The sum of cast masses were lower than data obtained by Norgrove and Hauser (2000), who reported 30 to 35 t ha^{-1} in agrisilvicultural systems in Central Cameroon, but much higher than the quantity of 2.6 to 5.7 t ha^{-1} deposited within 5 months on Ultisol in South East Nigeria (Henrot and Brussaard, 1997) and 5.9 t ha^{-1} after two years reported by Kanmegne (2004) in slash and burn agriculture in Southern Cameroon. Our maximum is 15 t ha^{-1} in cassava fields after 5 months sampling, and 4.2 to 6.7 t ha^{-1} in egusi melon, 10.5 t ha^{-1} in maize and 8.5 t ha^{-1} in cowpea fields for 2 months sampling. The higher earthworm activity in the cowpea than in the egusi melon fields may be explained by the higher quality of cowpea leaf litter compared to that of egusi melon (C/N of 14 against 27-37; Saïdou *et al.*, unpublished). In the more intensive cropping systems (maize field) earthworm activity was high, possibly related to the quantity of litter that is added to the soil during weeding. But with more weeding there could also be less shade and less moisture, factors that could reduce earthworm activity. Lavelle and Pashani (1989), working in the Peruvian Amazon, found that in traditional cassava and high input maize systems earthworm biomasses were 42 and 13% of that in forest fallow. Our results with cast production and cast nutrient concentration in the cassava and maize fields were quite close to those reported by Norgrove *et al.* (1998).

As reported by Henrot and Brussaard (1997), Norgrove et al. (1998), Hauser and Asawalam (1998), Norgrove and Hauser (2000), and Kanmegne (2004), casts were richer in total N, exchangeable K^+, Ca^{2+} and Mg^{2+} concentration than the topsoil. Casts from cowpea fields showed higher total N and exchangeable K^+ concentration than casts from the remaining fields. This effect is mainly due to the higher N and K concentrations in cowpea leaf litter compared with the egusi melon (33.1 and 16.5 g kg^{-1} respectively against 10.0-16.3 and 6.7-9.8 g kg^{-1} respectively; Saïdou et al., unpublished). Relationships between the quality of litter and earthworm activity and cast richness were also reported by Cortez and Bouché (1992), Tian et al. (1997), Cortez (1998), Brown (2000), Lavelle et al. (2001) and Birang et al. (2003b).

While casts were generally richer in nutrients than the topsoil, the degree of enrichment as a function of inherent soil fertility was variable. Such a relationship has often been depicted by a graph that plots the cast : top soil ratio as a function of the concentration of the soil (Hauser and

Asawalam, 1998; Norgrove and Hauser, 2000). However, in such plots a significantly negative power function results if cast enrichment is independent of soil properties. It is therefore more illuminating to plot topsoil versus cast properties. These plots (Figs. 1 and 2) showed contrasting effects between the cassava system and the egusi melon-maize-cowpea system. In the cassava systems cast enrichment was stronger in poorer soils for total N and Ca^{2+} concentration, while P-Bray 1 and exchangeable Mg^{2+} concentrations in casts scaled almost linearly with that in the topsoil. In the egusi melon system, cast enrichment was strongest in poorer soils for P-Bray 1, while Ca^{2+} concentration scaled almost linearly with that in the topsoil. These results with the egusi melon fields may be dependent upon initial soil condition (Hauser and Asawalam, 1998). In general, the results of the two experiments were comparable to those reported by Lal and De Vleeschauwer (1982), Hauser (1993) and Hauser and Asawalam (1998) in short fallows and cropped fields on Alfisol in South Western Nigeria and by Norgrove and Hauser (2000) in a 17 years old *Terminalia ivorensis* (Black afara) plantation in the Mbalmayo forest reserve in southern Cameroon.

Concentration of total N in the casts, except for casts in cowpea fields, was lower than 1.24 to 3.09 mg g^{-1} reported by Norgrove et al. (1998) and than 2.34 to 3.36 mg g^{-1} reported by Norgrove and Hauser (2000). This difference is likely related to the amount of legumes (and hence legume leaf litter) in the cropping system. Exchangeable K^+ was much higher than 0.069 to 0.142 mg g^{-1} reported by Norgrove and Hauser (2000) and similar to 0.18 to 0.27 mg g^{-1} and 0.12 to 0.19 mg g^{-1} reported by Norgrove et al. (1998) in Chromolaena (Siamweed) (bush and secondary forest respectively). Concentrations of exchangeable Ca^{2+} and Mg^{2+} in the casts and topsoil in the cassava fields were higher than those of egusi-maize-cowpea experiment. Because cassava is known to tolerate low Ca amounts in the root environment better than most other crops (Norman et al., 1995), we cannot explain these higher amounts. The Ca^{2+} concentration in the casts in cassava fields was similar to the 0.67 to 1.19 mg g^{-1} reported by Norgrove and Hauser (2000) but lower than 3.85 to 4.38 mg g^{-1} and 2.44 to 5.46 mg g^{-1} reported by Norgrove et al. (1998) in Chromolaena and secondary forest respectively. Those concentrations from egusi-maize-cowpea fields were much lower than those reported by Norgrove et al. (1998) and Norgrove and Hauser (2000). Mg^{2+} concentration in the egusi-maize-cowpea experiment was similar to the figures of 0.195 to 0.292 mg g^{-1} reported by Norgrove and Hauser (2000) and much lower than 0.64 to 0.83 and 0.51 to 0.73 mg g^{-1} reported by Norgrove et al. (1998) in Chromolaena and secondary forest respectively.

Linking farmers' perceptions and beliefs with results of field experiment

Farmers correlated earthworms with soil fertility. They were also aware of the higher nutrient concentration in the casts compared with the topsoil. However, their terminology of earthworm casts as a kind of vitamin did not necessarily reflect knowledge of a causal role for earthworms in enhancing soil fertility. That causal role may be important for subsequent discovery learning. The contracts to experiment together with farmers have been successful and provided rich experience for both researchers and farmers in terms of knowledge exchange. They also gave farmers more self-confidence. In meetings they had the opportunity to explain their perceptions after which the researcher provided additional information and explanation from formal science. Explanations by farmers were taken seriously by scientists, while the input from science was taken seriously by farmers. Farmers' interest in the beneficial effects of earthworms was therefore increased and this could be relevant when it comes to improving their soil fertility and cropping management practices.

Conclusion

Farmers in the transitional zone of Benin, like most other farmers in Africa, are knowledgeable on the role of earthworms and their casts due to their activity as indicator of soil fertility. Farmers ranked casting intensity in fields with different crops mainly on the basis of ground cover (shading) by the plant leaves. Farmers also reported that earthworms play a role in litter decomposition. But there was sometimes a misconception that earthworms are harmful because they are supposed to damage crop roots, a misconception that appears to relate to their observation of earthworms feeding on dead roots. Farmers also perceived casts as a kind of vitamin because casts are richer in nutrient than the underlying topsoil (0-10 cm depth), especially when the topsoil is relatively poor.

The participatory approach was a rich experience for both researchers and farmers. Most farmers confided that they have never been involved in research on earthworms before. Indeed, the stakeholder learning group was seen by them as a learning space where they had an opportunity to exchange knowledge with the researchers and also to learn from individual experiences about biological processes. It has increased farmers' self-confidence. It formed a good basis for the continuation of the research program, jointly agreed upon by farmers and scientists, which aims to determine the subsequent crop response after extensive cassava or egusi melon.

Chapter 4

Differential effect of cassava cultivars on subsequent maize yield through carry-over effects of arbuscular mycorrhiza

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Chapter 4

Differential effect of cassava cultivars on subsequent maize yield through carry-over effects of arbuscular mycorrhiza

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Abstract

It has often been alleged that cassava planting depletes soils of fertility. Farmers in central Benin make an opposite claim. According to them, planting a field with cassava prior to planting maize improves soil fertility. We investigated on-farm and in pot experiments the differential effect of three cassava cultivars (odongbo, Ben 86052 and Bouaké). We also tested whether a dose of 100 kg ha^{-1} NPK-SB 14-23-14-5-1 fertiliser applied to subsequently planted maize improves plant performance and affects incidence of arbuscular mycorrhizal fungi (AMF). Cassava cultivar, soil depth and farmer management all significantly affected the number of AMF spores in soil. Spore abundance was significantly negatively correlated with pH (H_2O), P-Bray1 and total N. The cassava cultivars did not change significantly soil chemical properties. However, cassava cultivar, fertiliser, and farmers' management affected significantly maize grain yield. Fertiliser application significantly increased maize yield with 50% compared with the unfertilised field. Cassava cultivar and farmers' management significantly affected uptake of N, P and K, whereas fertiliser treatment significantly affected only N and P uptake. Visual inspection of maize leaves in the field suggested both P and N limitation. N:P ratio of maize indicated that P was the main limiting nutrient. In contrast, N was most limiting in the pot experiment. Both prior planting of cassava cultivars and fertiliser significantly affected maize root and shoot production in pots. Fractional colonisation of maize roots by AMF ranged from 23 to 38%. Neither cultivar and fertiliser, nor farmer management, affected maize root length colonised by AMF. Fractional maize root colonisation by AMF was marginally significantly correlated with root fresh weight, shoot, and N, P, and K content of the shoot.

Keywords: extensive cassava, soil fertility, arbuscular mycorrhiza, yield improvement, nutrient uptake, Benin.

Introduction

Numerous rural development projects have been designed and carried out in the tropics with the intention of increasing agricultural production. Considerable technical and economic resources have been utilised, but the results achieved rarely approached the production increases originally expected (Honlonkou, 1999; Douthwaite *et al*., 2002). It has been argued that this failure is, to a significant degree, due to the lack of understanding of the ways that local farmers manage local agro-ecosystems, as well as misapplication of technologies by ultimate users (Bationo *et al*., 1998; Sanchez and Jama, 2002). Many technologies did not address farmers' needs and problems. They also failed to integrate well with indigenous knowledge and potential solutions already available to farmers. A key issue is therefore to make a proper experimental assessment of some of the claims of indigenous knowledge.

A diagnostic study carried out in the Atacora region and the transitional zone of Benin (Saïdou *et al.*, 2004) revealed that farmers had developed several alternative practices to enhance crop production. Farmers claimed that extensive cassava cropping systems, known in French as *jachère manioc* (cassava fallow) improve the soil. Strictly speaking, such systems are not fallows, as crops (cassava) are grown for 18-24 months. In extensive cassava systems earthworm activity is intense (Chapter 3) leading to efficient recycling of nutrients through their casts. This intense biological activity could contribute to the enhancement of yields of succeeding crops, as reported by Hauser *et al*. (1997), Norgrove and Hauser (1999), and Birang *et al*. (2003a). Indigenous practices based on soil biological activity provide feasible alternative land use strategies in the context of maintaining soil fertility (or reducing soil fertility losses) through low-external-input technologies within the prevailing socio-economic and cultural setting.

While farmers believe and claim that cassava could contribute to maintaining soil fertility (Hinvi, 1990; Saïdou *et al*., 2004; Adjei-Nsiah *et al*., 2004), conventional formal research has sometimes stated that cassava depletes the soil (Silvestre, 1987; IITA, 1990; Sitompul *et al*., 1992). However, claims that cassava is a soil miner seem partly based on observations that cassava grows on the poorest soils. This might be a case in which correlation is not a good guide to cause. An alternative explanation could be that cassava is grown on such soils because it tolerates (and subsequently extracts) lower amounts of nutrients than most other crops (Howeler, 2002). By itself, the contrast between scientific claims and farmers' understanding merits investigation. The ability of cassava to grow on poor soils is due to the fact that cassava is highly mycotrophic, depending on its ability to form arbuscular mycorrhiza (AM) (Kang *et al*., 1980; Habte and Byappanahalli, 1994; Fagbola *et al*., 1998; Howeler, 2002; Salami and Osonubi, 2002; Cardoso and Kuyper, 2006). The ability of AM fungi to increase uptake of relatively immobile nutrients, in particular P and several micronutrients, and transfer these to the plant in exchange for carbon is the most recognised beneficial effect of mycorrhizal associations. Mycorrhizal associations have a number of further beneficial effects on plants, such as improved water relations, especially under conditions of nutrient stress (Gueye *et al*., 1992; Augé, 2001). Beneficial effects of AM fungi on cassava might further translate into positive effects of cassava on a subsequent crop. This is the nub of the claim by farmers.

The larger project of which this study is a part aims to link, in a common framework, farmers' notions with theories of conventional science. In this case, our focus is on the potential of extensive cassava systems to enhance yields of a subsequent crop. More specifically, the present study aimed to: (1) assess soil chemical properties in extensive cassava cropping systems with different cassava cultivars, (2) assess mycorrhizal activity in different cassava cultivars, (3) assess nutrient uptake and yield of subsequent maize after planting different cassava cultivars, and (4) study mycorrhizal incidence on the subsequent maize crop. One aspect of the methodology of the Convergence of Sciences Programme (Röling *et al*., 2004; Hounkonnou *et al.,* 2006) is to locate points of convergence between farmers' knowledge and conventional science, and between natural and social sciences, which can be used as frameworks within which to introduce to and discuss with farmers basic scientific concepts. Here we have sought to engage with farmers around the theme of mycorrhizal associations. The basic idea is to make scientific experimentation transparent to farmers, and to engage farmers in such experimental activity. It was in order to allow farmers to form a clearer view of the magnitude of the effects of enhanced biological activity on crop yield that we also applied a minimum NPK-SB fertiliser, to enhance visibility of effects and make comparisons clearer. However, the study was not a trial or demonstration of NPK-SB effectiveness as such.

Material and Methods

Study site

The study was carried out in farmers' fields at Ouoghi central (8°07' N, 2°33' E) in the transitional agro-ecological zone of Benin. The area is at an altitude of about 200 m a.s.l. It has a Guinea-Sudan climate with a unimodal rainfall pattern. Average annual rainfall and temperature are 1100 mm and 27.5°C, respectively. Rainfall at the site lasts from April to mid-November. The soil is dominated by tropical ferruginous soils (Dubroeucq, 1977) derived from Precambrian crystalline rocks (granite and gneiss) of the African Basement Complex, classified as Ferric Lixisol (FAO, 1990).

Farmer participation in the research activities

After the diagnostic study (carried out from April to December 2002) a stakeholder learning and research group (SLG) for knowledge exchange was established in the village. Institutional development is a key aspect of creating a level playing field for assessing farmer and scientific knowledge claims, and in making science 'visible' to farmers. The forum involved on average 15 farmer innovators and the local extension agent. They met twice a month to discuss issues related to the experiments on soil fertility management practices. Farmers interested in the research activities entered the group of their own volition. The aim of the SLG was to enhance a joint learning process (*i.e.* researchers and farmers engaging in mutual learning and in discussions on an equal basis) which should contribute to democratisation of science. Such an action-oriented methodology, using an interactive approach, has as its target to enhance farmers' knowledge on the processes contributing to plant nutrition. The institution formed for this project was ad hoc, but can be compared to farmer knowledge formation processes under the more general label of Farmer Field Schools.

In the spirit of democratisation of science the research agenda and data to be collected were 'negotiated' with farmers. We decided to also use farmers' criteria to evaluate the effectiveness of an innovation. These criteria included colour of plant leaves (yellow leaves and purplish leaf discolorations suggesting nutritional constraints – note that farmers did not ascribe yellow colours to N deficiency and purplish discolouration to P deficiency), cob size, and grain yield. In the traditional cropping system, the stover is neither removed nor burnt when clearing the field for the next crop. Because such practices do not lead to nutrient depletion, only maize grain yield was determined. Farmers were involved in soil sampling and root collection for the assessment of mycorrhizal incidence in the laboratory. The research process ended in a feedback section, when the results of the experiment (crop performance, soil chemical properties, nutrient uptake by the crop, and mycorrhizal incidence) were presented to farmers and discussed.

Before the experiment was started we asked the farmers to rank three different cassava varieties regarding their potential to raise yields of succeeding maize. The scoring method was designed to rank yield performance based on farmers' perceptions. The three cassava cultivars identified were: odongbo (a local landrace), Ben 86052 (an improved fast-growing and high-yielding landrace introduced by the extension service) and Bouaké (a local landrace introduced from Côte d'Ivoire through farmers' networks).

Experimental set up

The study comprised an on-farm experiment under farmers' conditions and a pot experiment carried out with the SLG members in the village. The fields had been cultivated since 1999 according to local cropping practices (Saïdou *et al*., 2004). Cassava was planted in 2002, intercropped with maize or egusi melon or cowpea. After harvesting the crop, cassava was monocropped for a further year. In these fields the study on earthworm activity was also undertaken (Chapter 3). The experimental design was a completely randomised bloc design with three cassava cultivars as treatments. For each treatment, four farmers' fields were selected, leading to 12 plots in all. As in the traditional cropping system field variation is very important in terms of microvariability, labour management, farmer competence or skill, we did not consider the fields of different farmers as true replicates. Because cassava fine roots do not explore more than 40 cm of soil depth (Saïdou, unpublished), soil samples were collected at 0-10, 10-20, and 20-40 cm depth, at approximately 5 to 8 cm of the cassava stem for the study of AMF incidence.

We also tested whether a minimal dose of 100 kg ha^{-1} of NPK-SB 14-23-14-5-1 fertiliser (14 kg N, 10 kg P and 11.5 kg K ha^{-1}) applied to the subsequent maize crop improved plant performance and affected mycorrhizal incidence. After harvesting cassava and collecting fine roots for the assessment of AM colonisation, each field was split into fertilised and non-fertilised sub-plots. The experiment comprised 24 sub-plots. Each sub-plot was 45.5 m^2 (7 m x 6.5 m). Soil samples were collected at a depth of 0-20 cm for chemical analysis and for the pot experiment before sowing maize. An early maturing (3 months cycle) maize cultivar, DMR-SRW, provided by the extension service, was sown on July 2004 and fertiliser was applied three weeks after sowing. Ploughing, sowing and weeding were done by each individual farmer. The researcher provided maize seed and mineral fertiliser. Harvest and determination of yield parameters were done together with the members of the SLG.

Cob width was measured at the base of the cob. It is the part where the maize cob is much thicker than the superior part. Cob length was measured from the cob base to the last grains on the top. The measurements were carried out on 8 randomly selected, fully filled cobs because farmers do not take account of non-filled cobs. As sampling of fine roots for the assessment of AMF colonisation is destructive, and thus might lead to lowered maize yields, AMF root colonisation in maize was not assessed in the plants of the on-farm experiment but in the plants of the pot experiment.

The SLG was also involved in carrying out the pot experiment. Soil samples were crushed to pass through a 2 mm sieve. Portions of 3 kg air-dried soil were transferred into 3 litre plastic pots. The field capacity of the soil varied between 29-38 %. It was kept at field capacity by regular water supply with distilled water when water stress occurred. The pots were watered with a quantity of water equivalent to1/9 of the field capacity (100-125 ml of distilled water). 12 days after sowing a quantity of 115 mg of NPK-SB fertiliser (equivalent to 100 kg ha^{-1}) was applied to each fertilised pot. Maize was sown at 4 cm depth with 3 seeds per hole. 10 days after sowing, only 2 plants were left per pot. The harvest was done 30 days after sowing.

After washing the roots over a 0.5 mm sieve, fresh weight of shoots was determined. The fresh roots were sent to the laboratory and stored in a fridge. Root samples were kept in the fridge for three days. Shoot samples were dried at 70°C until constant weight and then dry weight was determined.

Soil and plant analysis

Soil and plant chemical analyses were performed in the Laboratory of Soil Sciences of the Faculté des Sciences Agronomiques of the University of Abomey Calavi and at the Laboratoire des Sciences du Sol, Eau et Environnement of Benin National Research Institute (LSSE/INRAB). Soil analyses were carried out on pH (H_2O) (using a glass electrode in 1:2.5 v/v soil solution), total N (Kjeldahl digestion in a mixture of H_2SO_4-Selenium followed by distillation and titration), available P (Bray 1 method), exchangeable K^+ (with 1 N ammonium acetate at pH 7, after which K was determined by atomic absorption spectrophotometry), NO_3^--N and NH_4^+-N in 1M KCl extract (NO_3^--N after adding MgO and distilling the mixture followed by titration; NH_4^+-N by adding to the preceding mixture Devarda alloy after which the new mixture was distilled followed by titration).

Total N in the plant was analysed by wet digestion in a mixture of H_2SO_4-Selenium followed by distillation and titration, K was measured by atomic absorption spectrophotometry. Determination of P included two steps, dry ashing a plant sample in a muffle furnace at 550°C for 4 h and gathering the residues in 1N HNO_3 involving a period of heating. P was subsequently measured colorimetrically by ammonium molybdate with ascorbic acid at a wavelength of 660 nm.

Assessment of AMF incidence

Both spore numbers and root colonisation by AMF were considered as indicators of mycorrhizal incidence (Onguene, 2000; Cardoso *et al.*, 2003). Spore extraction was done by wet-sieving (Brundrett *et al.*, 1996). The procedure was repeated until clear floating liquid was obtained. Spores collected were counted in a gridline Petri dish under a stereomicroscope at x 40 (Stemi DRC Zeiss). Only apparently healthy spores were counted. Spores were not identified.

Fine roots were cleared and bleached (successively with 10% KOH in a water bath at 90°C for 30 minutes, rinsed with water, and finally with 10% H_2O_2) and stained with 0.03% w/v Chlorazol black E in a lactoglycerol solution (1:1:1 lactic acid, glycerol and distilled water) (Brundrett *et al.*, 1996). The proportion of root length colonised by AMF was determined by the gridline intersection method (Giovannetti and Mosse, 1980).

Statistical analysis

Statistical analyses were performed using the SAS v 8.1 package. Soil chemical properties and fractional AM colonisation of cassava roots were subjected to a two-way analysis of variance (ANOVA) with cassava cultivar and farmer (management) as factors. Spore numbers of AMF in the soil were ln-transformed to meet ANOVA assumptions. The numbers of AMF spores were subjected to three-way ANOVA, with cassava cultivar, soil depth, and farmer (management) as main factors. Maize yield parameters (cob length and width and grain yield), nutrient concentration, nutrient content of the grain, and data of pot experiment were also subjected to a three-way ANOVA with preceding cassava cultivar, fertiliser treatment, and farmer (management) as main factors. Fractional AM root colonisation data were arcsine square root transformed to meet the assumptions for ANOVA. The Student Newman-Keuls test was performed to compare differences in means among treatments. Pearson's correlation coefficients were calculated between fractional root colonisation of maize, and soil properties, root weight, shoot weight and nutrient uptake. All significance levels were set at $P < 0.05$.

Results

Farmers' perceptions of the performance of the different cassava cultivars in enhancing the yield of succeeding crops.

Ranking done with members of the SLG showed that farmers (n = 15) were of the opinion that yield of the subsequent maize crop will be best enhanced by prior cropping with odongbo and least after prior planting with Bouaké. Farmers also claimed that odongbo would yield more than Ben 86052 and Bouaké. Their preferences for odongbo are explained by the facts that it stays in the field for a long period (at least 18 months) without rotting and that it produces more leaf litter; Ben 86052 and Bouaké are not resistant to rot. Ben 86052 and Bouaké are fast growing cultivars; they are in the field for a shorter period (6 to18 months) before harvesting and consequently produce less litter. Odongbo is the cultivar used by most farmers in the area; therefore abundant stalks are available for planting (cassava is vegetatively propagated from stem cuttings). Ben 86052 is a fast growing cultivar promoted by the extension service and the 'Projet de Développement des Racines et Tubercules' (PDRT) with delivery of planting material offered as part of a credit package. Bouaké (locally named *oni gbese duro demi,* lit. 'creditor waits in order to have your money') is also a fast growing cultivar introduced from Côte d'Ivoire within farmers' networks and mainly used to guarantee household food security.

Soil chemical properties and distribution of AMF spores in the extensive cassava cropping systems.

Soil pH (H_2O) was around neutrality. Soils of the plots planted with the various cassava cultivars varied significantly in pH (H_2O) while total N, NH_4^+-N, NO_3^--N, available P, and exchangeable K^+ did not vary (Table 1A). There were significant differences between farmers (*i.e.* between the plots

Table 1. (A) Two-way ANOVA (F-values) regarding preceding cassava cultivars and farmers' management practices. Figures in parentheses are probability of F-values. (B) Mean values (± standard error, n = 4) of soil (0-20 cm) chemical properties after harvesting the different cassava cultivar. In a column, means followed by the same letter are not significantly different ($P > 0.05$) (Newman-Keuls test). (Symbols for significance levels: * $P < 0.05$; ns not significant).

(A)

Source of variation	df	pH (H_2O)	P-Bray1	N-total	Exch. K^+	NH_4^+-N	NO_3^--N
Cultivar	2	9.18* (0.015)	3.28 ns (0.109)	2.11 ns (0.203)	1.81 ns (0.243)	0.08 ns (0.921)	0.70 ns (0.533)
Farmers' management	3	6.98* (0.022)	4.78* (0.049)	4.81* (0.049)	2.47 ns (0.160)	0.18 ns (0.908)	1.71 ns (0.263)

(B) *Cultivar*	pH (H_2O)	P-Bray1 (mg kg^{-1})	N-total (g kg^{-1})	Exch. K^+ (cmol kg^{-1})	NH_4^+-N (mg kg^{-1})	NO_3^--N (mg kg^{-1})
Odongbo	6.7 ± 0.1 a	10.9 ± 2.1	1.3 ± 0.0	0.2 ± 0.0	5.4 ± 0.5	5.3 ± 0.2
Ben 86052	6.3 ± 0.0 b	7.0 ± 0.4	1.1 ± 0.1	0.1 ± 0.0	5.4 ± 0.4	5.4 ± 0.3
Bouaké	6.4 ± 0.1 b	10.3 ± 2.2	1.2 ± 0.1	0.1 ± 0.0	5.6 ± 0.2	5.8 ± 0.5

Table 2.Three-way ANOVA (F-values) of arbuscular mycorrhizal fungal (AMF) spores in the different soil layers (0-10, 10-20 and 20-40 cm) regarding cassava cultivar, soil depths and farmers' management practices. The values were natural log(n+1) transformed before analysis of variance. (Symbols for significance levels : ** $P < 0.01$; *** $P < 0.001$; ns not significant).

Source of variation	df	AMF spores	
		F-values	$P > F$
Cultivar	2	24.63***	< 0.0001
Depths	2	26.82***	< 0.0001
Farmers' management	3	14.06***	0.0003
Cultivar*Depths	4	2.31 ns	0.117
Farmers*Cultivar	6	5.52**	0.006
Farmers*Depths	6	1.39 ns	0.295

they farmed) with regard to pH (H_2O), total N and exchangeable K^+. pH (H_2O) was slightly higher in the soils planted to odongbo compared with soils planted to Ben 86052 and Bouaké (Table 1B).

Different types of AMF spores were observed in the different soil profiles, but spores were not identified to AM fungal species. Table 2 presents results of the three-way ANOVA regarding cassava cultivar, soil depth, and farmers' management. All three factors affected significantly spore abundance of AMF. The interaction between cassava cultivar and farmers' management was significant. Spore abundance in the Ben 86052 fields was significantly higher than that in odongbo and Bouaké fields (Fig. 1). With Ben 86052 and odongbo spore abundance decreased significantly from the top layer to the deeper layer while no significant change was noticed with Bouaké.

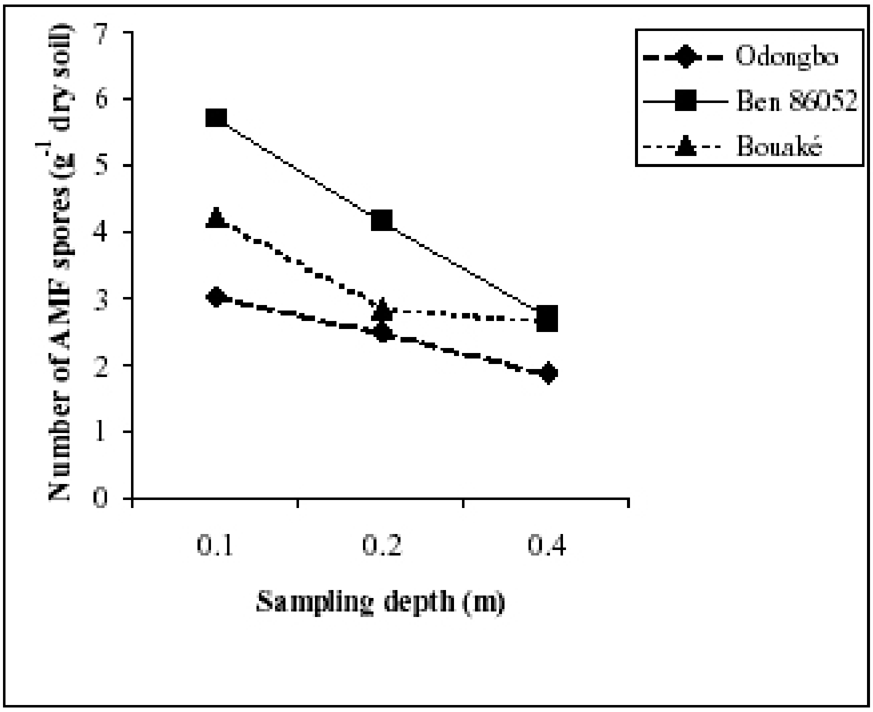

Figure 1. Number of spores of arbuscular mycorrhizal fungi regarding soil depth and preceding cassava cultivar.

Spore abundance of AMF in the 0-20 cm soil layer (combining numbers for depths 0-10 and 10-20 cm) were significantly negatively correlated with pH (H_2O) ($r = –0.86$, $P = 0.000$, $n = 12$), available P ($r = –0.795$, $P = 0.002$, $n = 12$), and total N ($r = –0.833$, $P = 0.001$, $n = 12$). Fractional root colonisation was neither significantly different between cassava cultivars (Fig. 2) nor correlated with soil parameters.

Performance of the subsequent maize crop

Three-way ANOVA of cob size and grain yield indicated significant effects of the three factors (cassava cultivar, fertiliser treatment and farmers' management), whereas the interaction between

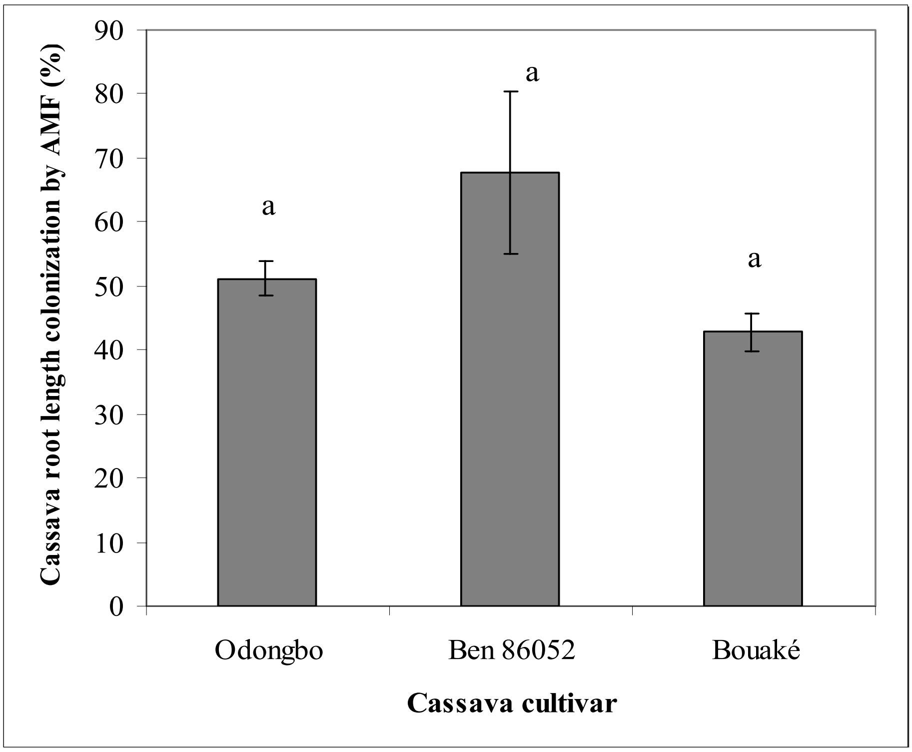

Figure 2. Fractional cassava root length colonisation by arbuscular mycorrhizal fungi. Vertical bars denote standard errors. Bars of the same types labelled with the same letter are not significantly different at $P > 0.05$ (Newman-Keuls test).

farmers' management and fertiliser treatment was marginally significant for cob width and grain yield (Table 3A). Grain yield and cob size were highest in the odongbo fields, consistent with farmers' claim. In the unfertilised fields cob length and width in the odongbo fields were significantly higher than those in the Bouaké and Ben 86052 fields (Table 3B). Grain yield in the odongbo fields was 50% higher (but only marginally significant) than in both Ben 86052 and Bouaké fields. In the fertilised fields grain yield significantly increased both in the odongbo and Bouaké fields, compared with the Ben 86052 field. The fertiliser treatment significantly increased overall grain yield with 50%. Based on the overall mean for unfertilised and fertilised fields, maize grain yields were significantly higher in the odongbo field than in Bouaké and Ben 86052 fields.

Three-way ANOVA of nutrient concentrations of grain indicated significant effects of prior cassava cultivar on K concentration, subsequent fertilisation treatment on N and K concentration and farmers' management on K concentration. There were no significant interactions between these factors (Table 4A). Neither cassava cultivar nor subsequent fertilisation treatment nor variation between farmers affected P concentration. Three-way ANOVA of nutrient (N, P and K) content of the grain indicated significant effects of fertilisation, preceding cassava cultivar and farmers' management (Table 4A). Mean values of nutrient concentration and content of the grain regarding preceding cassava cultivar and fertiliser treatment are presented in Table 4B. In the unfertilised treatment, K concentration in the odongbo field was significantly higher than that of Ben 86052 and Bouaké fields. Fertiliser treatment significantly increased N content of the grain with 80% in the plots where odongbo was the prior cassava cultivar, while K content of the grain in the fertilised plot was 70% higher in odongbo plots compared with plots with Ben 86052. Moreover, K content of maize grain in the unfertilised odongbo

Table 3. (A) Three-way ANOVA (F-values) of the cob length, cob width and maize grain yields regarding preceding cassava cultivar, fertiliser treatments and farmers' management practices. Figures in parentheses are probability of F-values. (B) Mean values (± standard error, n = 4) of subsequent maize cob length and width and grain yield regarding cassava cultivar and NPK-SB fertiliser treatments. In a column, means followed by the same letter are not significantly different (P > 0.05) (Newman-Keuls test). (Symbols for significance levels: $^{\dagger}P < 0.1$; $^{*}P < 0.05$; $^{**}P < 0.01$; ns not significant).

(A) *Source of variation*	df	F-values of cob size Cob length	 Cob width	F-values of grain yield
Cultivar	2	18.25** (0.0028)	7.07* (0.0264)	23.88** (0.0014)
Fertiliser treatments	1	20.61** (0.0039)	14.95** (0.0083)	39.09** (0.0008)
Farmers' management	3	2.12 ns (0.1989)	0.63 ns (0.6219)	19.99** (0.0016)
Cultivar*Fertiliser	2	2.60 ns (0.1535)	3.66† (0.0912)	2.95 ns (0.1280)
Farmers*Cultivar	6	1.87 ns (0.2328)	0.97 ns (0.5131)	3.20† (0.0913)
Farmers*Fertiliser	3	0.37 ns (0.7758)	4.87* (0.0476)	7.84* (0.0169)

(B) *Fertiliser treatments*	Cassava cultivars	Maize cob size (cm) Cob length	 Cob width	Maize grain yield (t DM ha^{-1})
Unfertilised	Odongbo	14.3 ± 1.0 a	14.6 ± 0.1 a	0.9 ± 0.1
	Ben 85052	9.7 ± 0.2 b	13.3 ± 0.3 b	0.6 ± 0.1
	Bouaké	11.6 ± 0.6 b	13.5 ± 0.3 b	0.6 ± 0.1
	P > F	0.0113**	0.0058**	0.0686†
Fertilised	Odongbo	15.0 ± 1.0	14.6 ± 0.4	1.3 ± 0.3 a
	Ben 85052	12.7 ± 0.6	14.2 ± 0.3	0.8 ± 0.2 b
	Bouaké	14.4 ± 0.2	14.6 ± 0.2	1.2 ± 0.3 a
	P > F	0.1057 ns	0.5761 ns	0.0186*

Table 4. (A) Three-way ANOVA (F-values) of N, P and K concentration and content in the subsequent maize grain regarding preceding cassava cultivar, fertiliser treatments and farmers' management practices. Figures in parentheses are probability of F-values. (B) Mean values (± standard error, n = 4) of N, P and K concentration and content in the subsequent maize grain regarding cassava cultivar and NPK-SB fertiliser treatment. In a column, means followed by the same letter are not significantly different ($P > 0.05$) (Newman-Keuls test). (Symbols for significance levels : † $P < 0.1$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$; ns not significant).

(A) *Source of variation*	df	F-value for grain nutrient concentration			F-values for nutrient uptake by grain		
		N	P	K	N	P	K
Cultivar	2	3.65† (0.0917)	1.25 ns (0.3521)	6.28* (0.0338)	14.19** (0.0053)	8.74* (0.0167)	20.90** (0.0020)
Fertiliser treatments	1	45.39*** (0.0005)	0.12 ns (0.7406)	166.53*** (< 0.0001)	47.88** (0.0005)	9.45* (0.0218)	127.89*** (<.0001)
Farmers' management	3	4.59† (0.0537)	0.13 ns (0.9402)	5.35* (0.0393)	14.50** (0.0037)	4.94* (0.0464)	21.48** (0.0013)
Cultivar*Fertiliser	2	1.67 ns (0.2650)	0.73 ns (0.5183)	2.30 ns (0.1811)	1.94 ns (0.2241)	1.45 ns (0.3067)	1.28 ns (0.3449)
Farmers*Cultivar	6	1.63 ns (0.2836)	0.80 ns (0 .6014)	0.32 ns (0.9060)	1.40 ns (0.3452)	1.30 ns (0.3785)	1.72 ns (0.2631)
Farmers*Fertiliser	3	0.66 ns (0.6035)	0.79 ns (0.5420)	3.31† (0.0987)	3.71† (0.0805)	1.20 ns (0.3863)	9.64* (0.0104)

(B) *Fertiliser treatments*	Cassava cultivar	Nutrient concentration in the grain (g kg^{-1})			Nutrient uptake by grain (kg ha^{-1})		
		N	P	K	N	P	K
Unfertilised	Odongbo	12.6 ± 0.5	6.1 ± 0.7	3.6 ± 0.2 a	11.9 ± 2.2	5.9 ± 1.3	3.4 ± 0.7 a
	Ben 86052	12.3 ± 1.0	5.6 ± 1.1	2.3 ± 0.2 b	7.1 ± 1.9	3.0 ± 0.5	1.2 ± 0.2 b
	Bouaké	12.2 ± 0.8	4.9 ± 0.3	2.7 ± 0.2 b	7.8 ± 0.7	3.1 ± 0.4	1.7 ± 0.2 b
	P > F	0.8693 ns	0.5573 ns	0.0170*	0.1234 ns	0.0729†	0.0189*
Fertilised	Odongbo	16.6 ± 0.3	6.8 ± 0.9	5.6 ± 0.4	21.6 ± 4.1 a	8.9 ± 2.1	7.5 ± 1.8 a
	Ben 86052	14.8 ± 0.8	4.6 ± 0.1	5.3 ± 0.4	11.8 ± 2.8 b	3.6 ± 0.7	4.3 ± 1.1 b
	Bouaké	14.3 ± 0.6	6.0 ± 1.1	5.2 ± 0.4	16.8 ± 3.2 ab	7.0 ± 1.9	6.1 ± 1.2 ab
	P > F	0.0800†	0.3146 ns	0.2474 ns	0.0116*	0.0634†	0.0198**

Table 5. (A) Three-way ANOVA (F-values) of visual observation in the field of subsequent maize leaf discolouration (yellowish and purplish colour) regarding preceding cassava cultivar, fertiliser treatments and farmers' management practices. Figures in parentheses are probability of F-values. (B) Mean values (± standard error, n = 4) of plants showing leaf discolouration regarding cassava cultivar and NPK-SB fertiliser treatments. (Symbols for significance levels : * $P < 0.05$; ** $P < 0.01$; ns not significant).

(A) *Source of variation*	df	Proportion of plant presenting yellowish leaves colour	Proportion of plant presenting purplish leaves colour
Cultivar	2	2.19 ns (0.193)	1.53 ns (0.290)
Fertiliser treatments	1	18.52** (0.005)	2.22 ns (0.187)
Farmers' management	3	8.98* (0.012)	9.03* (0.012)
Cultivar*Fertiliser	2	2.20 ns (0.192)	0.77 ns (0.503)
Farmers*Cultivar	6	2.55 ns (0.140)	4.70* (0.041)
Farmers*Fertiliser	3	0.69 ns (0.591)	1.40 ns (0.332)

(B) *Fertiliser treatments*	Cassava cultivars	Proportion of plant presenting yellowish leaves colour (%)	Proportion of plant presenting purplish-reddish leaves colour (%)
Unfertilised	Odongbo	39.9 ± 5.9	8.9 ± 1.7
	Ben	42.0 ± 9.8	5.9 ± 2.1
	Bouaké	45.7 ± 6.3	5.3 ± 1.4
	$P > F$	0.838 ns	0.260 ns
Fertilised	Odongbo	32.7 ± 5.8	8.6 ± 2.4
	Ben	15.0 ± 7.9	8.8 ± 4.5
	Bouaké	29.8 ± 10.5	7.5 ± 2.1
	$P > F$	0.144 ns	0.944 ns

plots was almost double that of unfertilised Bouaké and Ben 86052 plots. P content of the grain was marginally significant in both fertilised and unfertilised treatments. The interaction between farmers' management and subsequent fertilisation was significant for K content.

Table 6. Three-way ANOVA (F-values and F-probabilities) of maize fresh root and shoot grown in pots and fractional maize root colonisation by AMF regarding preceding cassava cultivar, fertiliser treatments and farmers' management practices. The values of fractional root colonisation by AMF were arcsine square root transformed before ANOVA. (Symbols for significance levels: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$; ns not significant).

Source of variation	df	Fresh root		Shoot		Fractional root colonisation	
		F	$P > F$	F	$P > F$	F	$P > F$
Cultivar	2	15.41**	0.004	37.29***	0.0004	1.16 ns	0.374
Fertiliser treatments	1	1.87 ns	0.220	16.84**	0.006	0.61 ns	0.465
Farmers' management	3	6.20*	0.029	10.57**	0.008	1.16 ns	0.399
Cultivars*Fertiliser	2	1.57 ns	0.283	0.79 ns	0.496	2.13 ns	0.200
Farmers*Cultivars	6	2.12 ns	0.191	2.55 ns	0.140	2.75 ns	0.122
Farmers*Fertiliser	3	0.51 ns	0.689	2.15 ns	0.195	0.76 ns	0.555

These data suggest that maize production in the field experiment was phosphorus limited. Fertiliser increased grain yield. P-concentrations did not change, but those of N and K did, suggesting luxury uptake. Visual observations indicated both purplish-reddish leaves (indicative of P deficiency) and yellowish leaves (indicative of N deficiency) (Table 5). However, the members of the SLG attributed the yellowish colour of the leaves to drought instead of to nutrient shortage. This attribution seems relevant because a period of drought was registered during the maize plant growth phase. Farmers indicated to have no explanation for these purplish-reddish discolouration. Fertiliser treatment (for yellowish leaves) and farmers' management (for both leaf discolourations) showed significant effects on the proportion of plants presenting these symptoms. The highest numbers of plants presenting these characteristics were observed in the unfertilised field.

Maize performance in the pot experiment

Root and shoot fresh weight of maize grown in pots containing soils from the different prior cassava cultivar plots were significantly affected by cassava cultivar and farmer management. Shoot weight, but not root weight was also significantly affected by fertilisation treatment. The interactions were not significant (Table 6). Root and shoot dry weight were significantly higher where odongbo was the prior cassava cultivar, consistent with the claim made by farmers (Fig. 3). Fractional mycorrhizal colonisation of maize roots ranged from 23 to 38%. Neither cultivar nor fertilisation nor farmer management affected maize root length colonised by AMF (Table 6).

Three-way ANOVA of nutrient concentration of maize shoots showed significant

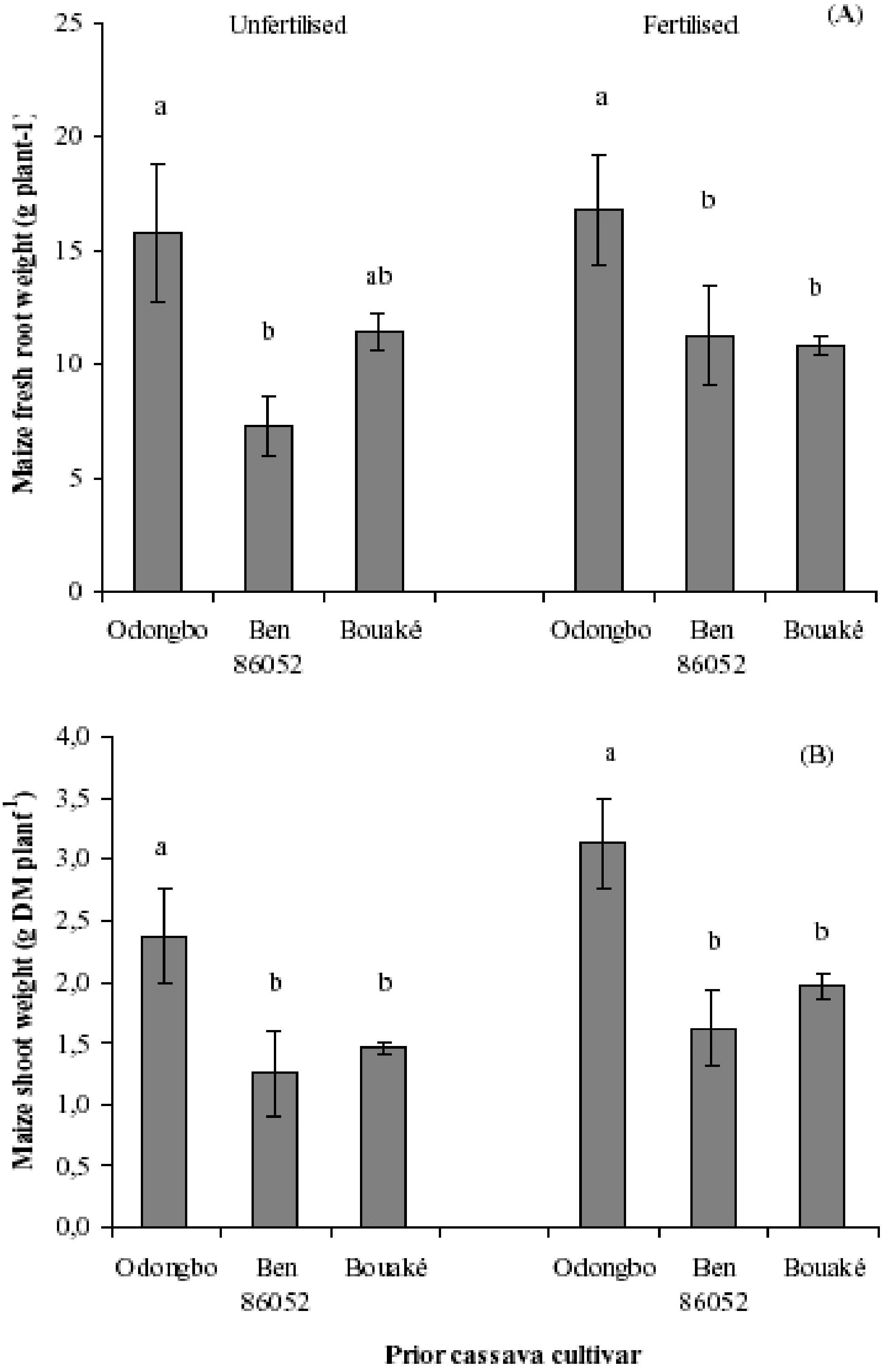

Figure 3. Pot experiment: (A) maize fresh root and (B) shoot weight regarding preceding cassava cultivar and NPK-SB fertiliser treatment. Vertical bars denote standard errors. Bars of the same types labelled with the same letter are not significantly different at $P > 0.05$ (Newman-Keuls test).

Table 7. (A) Three-way ANOVA (F-values) of N, P and K concentration and content in the maize shoot grown in pots regarding preceding cassava cultivar, fertiliser treatments and farmers' management practices. Figures in parentheses are probability of F-values. (B) Mean values (± standard error, n = 4) of N, P and K concentration and content in maize shoot grown in pots regarding preceding cassava cultivar and NPK-SB fertiliser treatments. In a column, means followed by the same letter are not significantly different (P > 0.05) (Newman-Keuls test). (Symbols for significance levels : † $P < 0.1$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$; ns not significant).

(A)	df	Nutrient concentration			Nutrient uptake		
Source of variation		N	P	K	N	P	K
Cultivar	2	0.58 ns	3.86†	28.03***	18.18**	38.75***	50.25***
		(0.5888)	(0.0838)	(0.0009)	(0.0028)	(0.0004)	(0.0002)
Fertiliser treatments	1	15.69**	130.98***	16.29**	17.26**	70.22***	5.38†
		(0.0074)	(< 0.0001)	(0.0068)	(0.0060)	(0.0002)	(0.0594)
Farmers' management	3	2.39 ns	2.40 ns	2.81 ns	4.20†	12.06**	7.51*
		(0.1724)	(0.1669)	(0.1301)	(0.0638)	(0.0060)	(0.0187)
Cultivar*Fertiliser	2	1.03 ns	4.93†	0.55 ns	1.29 ns	0.47 ns	0.26 ns
		(0.4126)	(0.0542)	(0.6025)	(0.3414)	(0.6451)	(0.7828)
Farmers*Cultivar	6	0.95 ns	4.62*	28.25***	1.62 ns	2.03 ns	1.80 ns
		(0.5223)	(0.0424)	(0.0004)	(0.2871)	(0.2053)	(0.2461)
Farmers*Fertiliser	3	1.56 ns	2.72 ns	1.55 ns	1.68 ns	2.99 ns	1.29 ns
		(0.2947)	(0.1372)	(0.2958)	(0.2701)	(0.1175)	(0.3603)

(B)	Cassava	Nutrient concentration (%)			Nutrient uptake (mg pot^{-1})		
Fertiliser treatments	cultivar	N	P	K	N	P	K
Unfertilised	Odongbo	1.1 ± 0.0	0.2 ± 0.0	3.7 ± 0.1	26.4 ± 4.6 a	5.1 ± 1.5 a	89.3 ± 17.1 a
	Ben	1.2 ± 0.1	0.1 ± 0.0	3.3 ± 0.5	14.2 ± 3.8 b	1.6 ± 0.5 b	36.2 ± 5.3 b
	Bouaké	1.2 ± 0.0	0.1 ± 0.0	2.9 ± 0.2	16.8 ± 0.7 b	2.1 ± 0.3 b	42.9 ± 2.7 b
	P > F	0.3988 ns	0.0535†	0.4302 ns	0.0375*	0.0190*	0.0057**
Fertilised	Odongbo	1.3 ± 0.1	0.3 ± 0.0	3.4 ± 0.1	41.3 ± 6.2 a	8.7 ± 1.2 a	105.6 ± 13.4 a
	Ben	1.2 ± 0.1	0.3 ± 0.0	2.9 ± 0.4	19.9 ± 4.2 b	4.3 ± 0.6 b	43.7 ± 4.2 b
	Bouaké	1.3 ± 0.0	0.3 ± 0.0	2.8 ± 0.2	25.8 ± 0.9 b	5.4 ± 0.6 b	54.3 ± 5.3 b
	P > F	0.5014 ns	0.9866 ns	0.4277 ns	0.0196*	0.0018**	0.0015**

Table 8. Pearson's correlation coefficients and probabilities between fractional maize of root colonisation by AMF and fresh root, shoot, N, P and K contents of maize grown in pots with soil from the different cassava cultivar regarding NPK-SB fertiliser treatments. Figures in parentheses are probabilities. (Symbols for significance levels: $^{\dagger}P < 0.1$; $^{*}P < 0.05$; ns not significant).

Fertiliser treatments	Root fresh weigh	Shoot	N uptake	P uptake	K uptake
Unfertilised	$0.55^{\dagger}$ (0.06)	0.58^{*} (0.04)	$0.56^{\dagger}$ (0.06)	0.70^{*} (0.011)	0.64^{*} (0.02)
Fertilised	0.32 ns (0.31)	0.13 ns (0.67)	0.06 ns (0.85)	0.24 ns (0.44)	0.13 ns (0.68)

effects of prior cassava cultivar (for K) and fertiliser treatment (for N, P and K), while farmers' management did not significantly affect nutrient concentration in the maize shoot (Table 7A). The interaction between farmers' management and preceding cassava cultivar was significant for P and K concentration. ANOVA of nutrient content in the maize shoot indicated significant effects of the prior cassava cultivar (for N, P and K), fertilisation treatments (for N and P) and farmers' management (for P and K). The interaction was not significant (Table 7A). The largest amounts of nutrients were taken up when the prior cassava cultivar was odongbo, both in the fertilised and unfertilised condition (Table 7B). The larger effect of fertilisation on P concentration than on N concentration and the rather low N:P ratio of maize shoots (around 5 in most cases) would suggest that nitrogen was more likely limiting than phosphorus in the pot experiment.

Fractional maize root colonisation by AMF was marginally significantly correlated with root fresh weight, shoot dry weight, and shoot N, P and K content in the maize shoot. In the fertilised pots, the correlations between fractional maize colonisation and plant performance were not significant (Table 8).

Discussion

Experimenting with farmers

Joint experimentation with farmers is sometimes considered difficult, because farmers are thought unlikely to grasp the statistical issues surrounding experimentation. Researcher-managed experiments in farmer's fields are for that reason sometimes preferred because replication is better achieved. In our case, we did not encounter problems in explaining the issue of variability (and hence the need for replication) to farmers. But even when this issue is resolved, translating this in an experimental set up is not always easy. Many farmers have only a small area on which to cultivate a number of crops, and it is often practically impossible to replicate experiments in different fields with equivalent previous histories, etc. By replication within a farmers' field one becomes guilty of pseudo-replication. So the usual way to solve this issue is by treating individual farmers as replicates, averaging out differences in farmers' practices and in site conditions. Such a practice does not match with farmers' understanding of variability. Farmers know that they are individually different in their practices, and are thus no replicates in the statistical sense. Due to differences between farmers and their practices, interaction terms between farmer practices and treatments can be highly relevant from the farmers' perspective, but disappear from sight in a conventional analysis of variance. For our joint experimentation we therefore decided not to treat farmers as replicates. We therefore had an unreplicated design and we tested for significant sources of variation against the highest interaction term. This procedure, while admittedly leading to loss of statistical power, does justice to farmers' perceptions of the way in which their individual practices and general treatments fit in a larger framework. The analyses in the present study suggest that farmer-to-farmer difference is an important source of variation. For the subsequent Student Newman-Keuls test, we did average out differences between different farmer practices, even though this entailed loss on information in our data set.

Soil chemical properties

Extractable P (6.9 - 10.9 mg kg^{-1}) in the cassava fields was equal to and lower than the 8 - 11 mg kg^{-1} and 10 - 25 mg kg^{-1} reported by Agbo (1999) in control plots and plots receiving mulch respectively. The higher available P and exchangeable K^+ found in the odongbo field may explain why subsequent maize yield was higher than in the Ben 86052 and Bouaké fields. The soil chemical properties did not match with the intensity of earthworm casting activity (Ben 86052 > Bouaké > odongbo; Chapter 3). The differences in soil data from the same fields reported in this study and the study on earthworm casting activity could be due to differences in sampling depth (0-20 cm in the present study against 0-10 cm in the study of earthworm casting activity).

Are soil chemical properties improved after extensive cassava? We admit that the present study does not provide a direct answer to this question. In fact, we tested differential effects of cassava cultivars, not effects of cassava per se. We noted differential effects of the various cassava cultivars. Farmers believe that the subsequent crop yield improvement is due to the potential of cassava to produce high amounts of leaf litter which on decomposing improves soil quality. Furthermore, Adjei-Nsiah (2006) in the forest/savannah transitional agro-ecological zone of Ghana noted that the local farmers provided the same reason as to why cassava-maize is the most preferred rotation among the natives. The leafy biomass, which is N-rich and decomposes rapidly, is returned into the soil in the form of green manure before the subsequent crop is planted. However, the study by Adjei-Nsiah (2006) was undertaken in rather fertile soils (to judge from cassava yields and nitrogen extracted – no P measurements were provided) where crop growth is usually N-limited. In the transitional zone of Benin with ferruginous soils P is more often the limiting nutrient.

In a similar study carried out in the transitional zone of Benin, Etèka (2005) found in tissue analysis of different cassava cultivars (stalk and tuber) relatively high amounts of N and K (37-65 kg N ha^{-1} and 90-132 kg K ha^{-1}) while the amount of P extracts was more modest (4-7 kg P ha^{-1}). These data suggest that cassava extracts relatively less P than N, which can contribute to better P nutrition for the subsequent cereal, especially when P is already limiting. As the nutrients in the tops are returned (when they are not used as planting material, the tops are burned during land preparation and the ash returned to the soil), actual extraction would be substantially lower. Howeler (2002) reported for unfertilised 12 months old cassava high N and K absorption by tops and the tubers (69 and 30 kg ha^{-1} N, and 34 and 55 kg ha^{-1} K respectively) while the amounts of P were roughly 7.5 kg ha^{-1} for both tops and tubers.

Maize yields after extensive cassava cropping with different cassava cultivars

The subsequent maize grain yield in the unfertilised cassava fields ranged between 0.6 - 0.9 t DM ha^{-1}. The relatively low grain yields could have been induced by drought which occurred during the tasselling period in September. However, the yield is similar to the yield (0.7 - 1.1 t DM ha^{-1}) reported by Houngnandan (2000) on degraded 'terre de barre' soils (further south) when mucuna mulch was applied on surface soil together with different sources of P. The yield is also similar to 0.6 - 1.0 t DM ha^{-1} reported by Hinvi (1990) in a cassava-maize rotation system in the south of Benin. In the locality of Agouagon in central Benin with the same soil type as our study area, maize following cassava performed as well as subsequent maize after alley cropping with *Acacia auriculiformis* and *Cajanus cajan* (1.0 and 1.1 t DM ha^{-1} respectively, Agbo, 1999). In order to know whether the extensive cassava cropping system performs, and could be used, as an alternative crop management strategy, the general trend of maize grain yield should be compared with other cropping systems such as continuous maize, cowpea – maize or maize – soybean rotation. IITA (1997) reported 0.7 t ha^{-1} of maize grain yield in a maize-maize rotation system with no additional fertiliser input, while maize crops planted after five different soybean varieties yielded 1.2 – 1.4 t ha^{-1}, depending on the soybean cultivar used. Maize grain yield in our study was comparable with the 0.7 t ha^{-1} and 0.9 t ha^{-1} reported by Carsky *et al*. (1999) in grass fallow - maize and cowpea – maize rotation systems respectively. Our data suggest that cassava does not deplete the soil, and that judicious choice of cassava cultivars in extensive cropping systems may be useful in maintaining reasonable yields. However, cassava does extract substantial amounts of K and the long-term sustainability of the cassava – maize system in soils, where K pools are small, warrant further study.

Fertilisers (which many, if not most, farmers in Ouoghi cannot afford) increase yields with 50%. These results are far lower than 0.9-3.6 t DM ha^{-1} reported by Agbo (1999) in a long-term experiment (1991-1996) in Agouagon region with yearly input of 90 kg N ha^{-1}, 39 kg P ha^{-1} and 75 kg K ha^{-1}, while a lower amount of N, P and K was applied in this study. Our maize grain yields in the fertilised field are close to 1.4 t DM ha^{-1} measured by Saïdou *et al*. (2003) on degraded 'terre de barre' of southern Benin with fertiliser input of 60 kg N ha^{-1}, 43 kg P ha^{-1} and 50 kg K ha^{-1}.

Cassava, a strongly mycorrhiza-dependent plant, is heavily colonised by AMF, which may mobilise more P that otherwise is not easily available to the plant. Several preliminary indications point towards a role for prior cassava in alleviating P stress in these soils. The N:P ratios of maize grain (*cf* also Saïdou *et al*., 2003) indicated that phosphorus is the main limiting nutrient. Visual inspection of leaf discolourations yielded mixed results. In the field, the fertilisation experiment showed increased nitrogen concentration in grain, but no changes in phosphorus (Table 4), suggesting that the phosphorus use efficiency did not change, while nitrogen was taken up in luxury amounts. However, the pot experiment (Table 7) suggested that N was most limiting. These results are possibly due to better watering condition in the pot experiment, shorter time duration of experimentation (30 days against 90 days for the field experiment) and higher root biomass in the pot experiment compared with plants in the field.

AMF and maize yield and nutrient uptake.

No significant differences were observed between fractional AM colonisation of maize in soils from the different cassava cultivars. Addition of minimum fertiliser also did not change fractional root colonisation. However, in the non-fertilised pots fractional root colonisation was significantly correlated with plant biomass and the uptake of the major nutrients N, P and K. It is likely that mycorrhizal carry-over effects of the previous crop, and / or differences in previous management directly contributed to the mycorrhizal benefit that maize derived. High mycorrhizal inoculum at the start of the growing season has major effects on the growth and phosphorus uptake of cereals and legumes (Miller, 2000; Goss and De Varennes, 2002). These results suggest, therefore, that the build-up of AMF inoculum by prior cassava is beneficial to the nutrition and productivity of subsequent maize. Mycorrhizal associations may be an important part of the explanation of why farmers claim extensive cassava cropping systems improve the subsequent crop yield. Sanginga *et al.* (1999) and Osunde *et al*. (2003) reported similar results with soybean. These authors demonstrated that AM colonisation in maize benefited from previously grown soybean plants and that the beneficial effects cannot be solely due to increased nitrogen availability after growing N-fixing legumes.

From a long-term perspective, the benefits provided by mycorrhizal associations to crops are based on their efficacy in mining nutrients. Therefore, the contribution of mycorrhizas to crop yield improvement should not be taken as a claim that mycorrhizal fungi can be considered biofertilisers. But in cropping systems where hyphae of AMF can enlarge the volume of soil explored and exploited for nutrients, AMF can enlarge crop productivity. In the case of the central zone of Benin, apart from the series of learning exercises on biological nitrogen fixation and AM symbioses (Saïdou *et al*., 2004), farmers are not yet convinced about mycorrhizal symbioses. They also lack the (financial) means to obtain mycorrhizal inoculum. As for scientists, they may not always appreciate the need for managing mycorrhizal associations. Possibly for that reason, Sanginga *et al*. (1999) claimed that AMF could be the most important untapped poorly understood resource for nutrient acquisition and plant growth in tropical agriculture.

As the farmers do not continuously cultivate on any piece of land to the same types of crop - a practice that leads to decline of AMF incidence or could select for less mutualistic fungi (Cardoso and Kuyper, 2006) - this actual type of land use we describe may be sustainable in the context of smallholder farming systems. Therefore, the management of cropping systems that benefit indigenous mycorrhizal inoculum may be a direct route towards sustainable soil fertility maintenance under prevailing local conditions in the central zone of Benin. At the feedback session in the village, photos of spores of AMF in the soil and hyphae and other mycorrhizal structures in the plant roots were shown to farmers. The contribution of mycorrhizal associations in nutrient, especially P, uptake was discussed with the members of the SLG. Farmers agreed to call mycorrhizas *a fun n'kin oko lodjè*, which literally means plant food provider in the local language (Tchabè, a dialect of Yoruba). As we are dealing with people who still believe in divine or supernatural causes of soil fertility (*cf* Chapter 3), further learning sessions need to be organised in order to explore with farmers the nature and significance of evidence regarding mycorrhizas on yield improvement.

Conclusion

The study provides evidence that maize yield improvement after prior planting of extensive cassava – something farmers in the transitional zone of Benin claim – may be due to the enhancement of AMF mutualistic symbioses. Nevertheless, the present study did not provide a complete answer to the question whether soil chemical properties are improved by prior extensive cassava planting. However, we have noted important differential effects associated with the various cassava cultivars. It seems possible these results may have an important implication for the understanding of the functioning of extensive cassava in traditional cropping systems. Implementing a joint learning process to further explore and research the beneficial effect of AMF in nutrient uptake in plant yield improvement might be relevant, therefore, in order to shift farmers' soil fertility management towards a more sustainable biological land management approach including the use of mycorrhizal plants in the cropping system. A second-order objective of the present piece of research has been fulfilled within the framework of the Convergence of Sciences Programme – namely to show that whereas farmer opinions and interpretations cannot be treated as data concerning cropping processes they can nevertheless be usefully woven into a well-controlled scientific research design as relevant pointers towards hypotheses that help uncover hitherto unknown facts and processes.

Chapter 5

Effects of farmers' fertiliser application practices and land use types on subsequent maize yield and nutrient uptake in central Benin

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Chapter 5

Effects of farmers' fertilisers application practices and land use types on subsequent maize yield and nutrient uptake in central Benin

Abstract

Farmers' knowledge and perceptions concerning the role of different nutrients in mineral fertiliser were assessed in central Benin, and four on-farm experiments in farmers' conditions examined whether land-use types and fertiliser treatments for prior cotton would sustain subsequent maize crop yields and achieve balanced nutrition. The treatments consisted of four prior land use types, *i.e.* before planting maize (egusi melon-cotton-cotton, cotton-maize-cotton, cassava-maize-cotton and groundnut-maize-cotton) including, for each, four replications of three fertiliser treatments (farmer fertiliser application practices): recommended practice [150 kg ha^{-1} of complex 14-23-14 (NPK) plus 5S-1B 25 days after sowing and 50 kg ha^{-1} of urea 40 days after sowing], NPK-SB mixed with urea (the recommended amount of NPK-SB and urea are mixed then applied 40 days after sowing) and reduced NPK-SB dose (recommended practice, but the amount of NPK-SB is reduced to 100 kg ha^{-1}). Farmers attribute plant growth and development to fertiliser, but do not differentiate the effects of the various nutrients (N, P, K). Furthermore, they are knowledgeable about fertiliser's residual effect. Lack of labour and need to maximise income in the short term force farmers to adapt technology to local environmental conditions. Prior cotton yields, subsequent maize yields and nutrient uptake were not significantly affected by fertiliser treatments. P-Bray 1 before planting the subsequent maize was significantly affected by fertilisation treatments while pH (water), total N, exchangeable K^+, NH_4-N and NO_3-N were not affected. Land use types had a significant effect on cotton yield, soil chemical properties, subsequent maize yields and nutrient uptake. The lowest yield and nutrient uptake were registered in the groundnut-maize-cotton land use succession and the highest in the egusi melon-cotton-cotton succession. The importance of co-operation between farmers and scientists in the design and execution of experiments is stressed.

Keywords: Farmer perception, crop rotation, technology adaptation, soil fertility, yield maintenance, nutrient balance.

Introduction

Agricultural production is for the majority of the West African rural population the major source of income in a rural livelihood portfolio that often includes other activities. Production increases are still largely based on the expansion of cultivated land rather than on increased productivity of the land currently under cultivation (Schreurs *et al*., 2002). Continuous cultivation without adequate replenishment of the natural resource base leads to soil degradation and nutrient depletion, and is a serious threat to sustained agricultural productivity. Research in sub-Saharan Africa today focuses on the combined application of organic residues and mineral fertilisers as a way to arrest ongoing soil fertility decline (Janssen, 1993; Vanlauwe *et al.*, 2001; Iwuafor *et al*., 2002; Schreurs *et al*., 2002; Place *et al.*, 2003). There is widespread recognition that neither method alone will be successful, in many cases. Technologies associated with the 'Green Revolution' that rely purely on substantial use of mineral fertiliser have failed to take hold in Africa (Giller, 2002) due to problems related to the cost and availability of inputs.

Access to mineral fertilisers in rural areas has been considerably affected by introduction of structural adjustment programs requiring liberalisation of input delivery services (Adégbidi *et al*., 2000; Vanlauwe and Giller, 2006). Such economic reform programs have helped to stabilise the economy of most of the African countries (Orr, 2000). They emphasise liberalisation of agricultural marketing, and embrace not only questions of pricing policy, subsidies and exchange rates but also call for a radical increase in the role of the private sector in agriculture (Shepherd, 1989). In the broader context of structural adjustment policy, governments are committed to reduce the subsidy on fertiliser as a proportion of the economic cost and as a share of government expenditure. In Benin, progressive reduction in fertiliser subsidy and the devaluation of the CFA Franc by 50% (the common currency for francophone West African countries supported by France) in January 1994 imposed much higher fertiliser costs on smallholders (Adégbidi *et al*., 2000). The result was a sharp increase in costs of cash crop production, especially cotton. At the same time devaluation of the CFA Franc raised imported farm input costs. Cotton prices increased, but this has been insufficient to compensate for the increased fertiliser prices (Sahel and West Africa Club, 2005; Benjaminsen *et al*., 2006). Farmers now had stronger incentives to carefully determine their usage of mineral fertiliser, and this appears to have guided adaptation of mineral fertiliser technology.

The incentive to use fertiliser more cost-effectively fits into a larger context for change within farming systems in central Benin in recent decades. Land is now more frequently cropped, in response to a range of external drivers. Perhaps the most important of these drivers is the migration flux in central Benin (Saïdou *et al*., 2004, 2006). Cotton production has expanded. Inputs (especially mineral fertiliser delivered as credit), efficient agricultural extension service, and well organised commercialisation channels have enhanced production. Fertiliser is mainly used for cotton, the country's main export crop. The availability of fertilisers in cotton-growing areas simultaneously allows limited fertiliser use on food crops, especially maize. Farmers also rotate cotton with maize in order to enhance cereal production through the residual effect of previous fertiliser (Saïdou *et al*., 2004). Such practice indicated the knowledge possessed by farmers concerning residual effects of fertilisers.

Farmers in the West African cotton belt (Fok *et al*., 2000; Benjaminsen *et al*., 2006) – and Benin is no exception – appear to be skilled in adapting fertiliser application practices. Instead of following the recommended practice, they slightly reduce the amount of NPK-SB (Adégbidi *et al*., 2000) or mix NPK-SB and urea fertiliser (Edon, 2003; Saïdou *et al*., 2004). These modified fertiliser application practices were introduced by migrants in order to make more profit from the land they rent (Saïdou *et al*., 2006). Native farmers have copied these practices. The practices are guided by economic incentives; both the need to reduce labour inputs (*i.e.* to reduce labour costs in the case of mixing fertilisers) and the need to reduce cash outlays (fertiliser input is delivered as credit so farmers reduce the quantity of fertiliser used and increase margins when they sell their cotton). Because nitrogen is easily lost under tropical conditions (Pieri, 1989; Oikeh, 2003) through volatilisation and leaching these novel practices – while helping ease labour and cash shortages – may have adverse effects in terms of subsequent food crop yields.

Are these innovations in fertiliser use distress adaptations with negative longer term consequences, or have farmers discovered some genuinely more effective ways to make best use of limited input supplies? Soil scientists may be tempted to assume the former. But agricultural science has repeatedly failed to understand the nature of rural people's knowledge (Scoones and Thompson, 1994). For many, what rural people know is assumed to be 'primitive' and 'unscientific' (Pretty, 1995), and so formal research and extension must transform what they know, in order for communities to develop. A different approach assumes that local agricultural knowledge is a valuable and under-utilised resource, and efforts should be made to incorporate it into development activities. The overall methodology of the Convergence of Sciences project, of which this study is a part, seeks better integration of viable local knowledge and science-based technology (Hounkonnou *et al.,* 2006). A key issue for the approach is to make a proper experimental assessment of some of the claims based on farmers' knowledge and technology adaptation.

Understanding farmers' practices and the logic underlying them is useful in re-orientation of research in order to come up with new practices that are adapted to the constraints African smallholders face. We investigated the extent to which farmers' knowledge of nutrient management practices in cotton-based farming systems can sustain yields of a subsequent maize crop. Farmers' adaptive capacity is of interest in order to augment indigenous solutions to soil fertility management. The present research also intends to show how scientists can effectively experiment with farmers and improve the knowledge of both parties. The research process was carried out using an interactive approach that stressed experiential and collaborative learning and knowledge exchange within a stakeholder learning group (SLG). Specifically, the research aimed: (i) to assess farmers' perceptions and knowledge of the role and residual effects of urea and NPK fertilisers (ii) to assess the effect of fertiliser treatments and land use types on soil chemical properties before planting a subsequent maize crop; and finally (iii) to determine the response of cotton and a subsequent maize crop to fertiliser application according both to recommended and farmers' actual practices.

Material and methods

Study site

The study was carried out in farmers' fields at Ouoghi central village (8°07' N, 2°33' E) in the transitional agro-ecological zone of Benin. The area is at an altitude of about 200 m a.s.l. It has a Guinea-Sudan climate with a unimodal rainfall pattern. Average annual rainfall and temperature are 1100 mm and 27.5°C, respectively. Rainfall at the site lasts from April to mid-November. The soil is dominated by tropical ferruginous soils (Dubroeucq, 1977) derived from Precambrian crystalline rocks (granite and gneiss), and classified as Ferric Lixisol (FAO, 1990). Soil particle size and chemical properties at the beginning of the experiment are presented in Table 1. The most important crops are maize, yam, cowpea, cotton, and groundnut. Cotton production is supported by a credit scheme for mineral fertilisers and pesticides, and a government-regulated market for selling the produce. The total population of the district amounts to 67,753 inhabitants. The average population density is about 30 inhabitant km^{-2} (INSAE, 2003). Migrants constitute 37% of the total population.

Table 1. Soil (0-20 cm) chemical and physical properties at the beginning of the on-farm experiment regarding the previous crop rotation types before cultivating the subsequent maize crop.

Farmers' fields and crop management types	Clay	Silt	Sand	pH	N-total	P-Bray 1	Exch. K^+
		(%)		(H_2O)	(g kg^{-1})	(mg kg^{-1})	(cmol kg^{-1})
Egusi-cotton-cotton	4.0	10.5	85.2	6.6	0.8	16.4	0.3
Cotton-maize-cotton	4.5	9.5	85.3	6.6	0.9	21.0	0.4
Cassava-maize-cotton	2	11.3	86.2	6.5	1.2	16.8	0.2
Groundnut-maize-cotton	3.2	8.1	88.5	6.4	1.2	24.2	0.3

Farmers' participation in the research activities

After a diagnostic study was undertaken (Saïdou *et al*., 2004), stakeholder learning groups (SLG) for knowledge exchange were established in the villages of Ouoghi Central, Ouoghi Gare and Boubouhou. Ouoghi Central is composed exclusively of native Tchabè people (sub-Yoruba group), while Ouoghi Gare and Boubouhou are mainly composed of migrants from Atacora-Donga (northern Benin) and the Abomey plateau (southern Benin), who have emigrated because of soil degradation in their home villages. The forum consisted of 20 farmer innovators producing cotton (6 in Ouoghi Gare and 14 in Ouoghi Central) and the local extension agent. At the same time group discussions with cotton producers were organised in Boubouhou. The SLG met twice a month to discuss issues related to the experiment. Discussions were held with the group in Boubouhou about farmers' perceptions concerning nutrient in mineral fertiliser and the role of mineral fertilisers. Farmers entered both groups of their own volition, to maximise chances they would have a genuine interest in research activities.

The aim of forming the SLG was to enhance a joint learning process whereby both researcher and farmers could learn from each other and engage in discussions on an equal basis (democratisation of science). Such a research method, using an interactive approach, aims to enhance farmers' and scientists' knowledge on processes contributing to plant nutrition. The research agenda and data to be collected were 'negotiated' (collectively agreed upon) with farmers. In the end, we also decided to use farmers' criteria to evaluate the effectiveness of the practices. These criteria include colour of plant leaves (green leaves indicating the well-being of the plant; yellow leaves and leaf discoloration suggesting nutritional constraints), cob size, and grain yield. As a surrogate of cob size we measured cob length and circumference (width). In addition to grain yield, yield of stover (leaves and stem), and soil and plant nutrient concentration were also measured, on a basis proposed by the researcher. The stover was measured to assess the nutrient balance.

Farmers were involved in soil sampling and yield measurements. The research process came to a conclusion in a feedback session where the results of the experiment (crop performance, soil chemical properties and nutrient uptake) were presented.

Experimental set up

The on-farm experiment under farmers' condition was jointly carried out with the SLG members. The fields had been cultivated since 1998 according to local cropping practices (Saïdou *et al*., 2004). As the farmers could not remember with precision the different cropping sequences since the period of first cultivation, we considered land use types over the two previous years *i.e.* 2000 and 2001. Four fields (belonging to two migrants and two native farmers) were selected with regard to previous land use types (LUT), *i.e.,* the cropping sequences widely practised in the area. Each field represented a specific cropping sequence before planting maize:

(1) egusi melon-cotton-cotton (selected in Ouoghi Gare);
(2) cotton-maize-cotton (selected in Ouoghi Central);
(3) cassava-maize-cotton (selected in Ouoghi Gare);
(4) groundnut-maize-cotton (selected in Ouoghi Central).

Planting, weeding, harvesting and frequency of weeding operations were left up to each farmer. The researcher provided only maize seed. The cotton was sole planted in July 2002 and harvested on January 2003. For each field (corresponding to a cropping sequence), the experiment was set up according to a completely randomised bloc design with three treatments consisting of farmers' fertiliser application practices. Each treatment was replicated four times (pseudo-replication, *i.e.* replication within a field). There was no replication of fields, because it was difficult to find fields with the same history and management type for comparison. We decided not to include a non-fertilised field as control because farmers consider such a control irrelevant, knowing already that a beneficial effect of fertilisers was certain to occur. Certain farmers even claimed that the cotton plant might not produce fibre without fertiliser and would fail to resist pest attack. Abstaining from fertiliser use is not advised at all by the extension service and also is not practised in the area. We took the recommended fertiliser application as the reference practice. The three treatments were:

(1) recommended practice, 150 kg ha^{-1} of 14-23-14-5-1 (NPK-SB) applied to cotton 25 days after sowing (DAS) and 50 kg ha^{-1} of urea applied 40 DAS; the amount of macronutrients applied were: 51 kg N ha^{-1}, 15.2 kg P ha^{-1} and 17.4 kg K ha^{-1};
(2) NPK-SB mixed with urea (the recommended amounts of NPK-SB and urea were mixed and then both applied 40 DAS);
(3) Reduced amount of NPK-SB (100 kg ha^{-1}) 25 DAS and 50 kg ha^{-1} of urea applied 40 DAS; the amount of macronutrients applied were: 44 kg N ha^{-1}, 10.1 kg P ha^{-1} and 11.6 kg K ha^{-1}.

Plot size was 100 m^2 (10 m x 10 m); the harvest area was 64 m^2 (8 m x 8 m). The prior cotton plant spacing was 0.2 m x 0.8 m with two plants per hole. Cotton fibre and stalks were assessed and sub-samples were collected and weighed. Dry matter was determined after drying at 60°C for 48 h and chemical analysis was performed on both materials. Composite soil samples were collected at a depth of 0-20 cm in each field at the beginning of the experiment, *i.e.* before planting the cotton. Soil samples were again collected in each sub-plot at a depth of 0-20 cm before subsequent planting with maize. The sampling was done along the tops of the ridges made for maize planting.

The subsequent maize crop was cultivated in accordance with farmers' practices, *i.e.*, without further fertiliser input. Seeds of an early maturing (3 months cycle) maize cultivar, DMR-SRW, provided by the extension service, were sown in May 2004 according to farmers' practices. Plant spacing was 0.7 m x 0.8 m with 2 to 3 plants per hole. Maize was harvested at physiological maturity in August 2004. Assessment of yield parameters (measurement of cob size, cob width, grain and stover weight) was done together with the appropriate SLG member. Weights were recorded in the field with a hanging scale. Samples of straw plus husk, and 8 cobs were randomly selected, weighed and the dry matter was determined after oven drying at 60°C for 48 h to a constant weight. Then seeds were removed from the cobs and the grain yield estimated. These samples were ground in a stainless steel mill in order to perform analysis of macronutrients. Cob diameter was measured at the base of the cob. It is the part where the cob is much thicker than the superior part. Cob length was measured from the cob base to the last ring of grains around the cob top. The measurements were carried out in the field on 6 randomly selected fully filled cobs because farmers normally do not consider the non-filled cob.

Soil and plant analysis

Soil and plant chemical analyses were performed in the Laboratory of Soil Sciences of the Faculté des Sciences Agronomiques of the University of Abomey Calavi and nitrogen concentration in the soil and plant tissue at the Laboratoire des Sciences du Sol, Eau et Environnement of Benin National Research Institute (LSSE/INRAB). Soil analyses were carried out on pH (H_2O) (using a glass electrode in 1:2.5 v/v soil solution), total N (Kjeldahl digestion in a mixture of H_2SO_4-Selenium followed by distillation and titration), available P (Bray 1 method), exchangeable K^+ (with 1 N ammonium acetate at pH 7, after which K was determined by flame photometer), NO_3^--N and NH_4^+-N in 1M KCl extract (NO_3^--N after adding MgO and distilling the mixture followed by titration; NH_4^+-N by adding to the preceding mixture Devarda alloy after which the new mixture was distilled followed by titration).

Total N in the plant tissue was analysed by wet digestion in a mixture of H_2SO_4-Selenium followed by distillation and titration. K was measured in the extract by flame photometer. Determination of P included two steps, dry ashing a plant sample in a muffle furnace at 550°C for 4 h and gathering the residues in 1N HNO_3 involving a period of heating. P was subsequently measured colorimetrically by ammonium molybdate with ascorbic acid at a wavelength of 660 nm.

Statistical analysis

Statistical analyses were performed using the SAS v 8.1 package. Soil chemical properties, yield parameters (cob length and width, grain yield and stover mass), macronutrient concentration in the plant tissue, and nutrient uptake, were subjected to nested analysis of variance (analysis based on an hierarchical classification model) (Cochran, 1967) regarding land use types and fertiliser treatments. This analysis was performed following the GLM procedure. Such nested designs arise in situations where replicate measurements are made on the same experimental unit. They superficially resemble randomised blocks designs but require alternative methods of analysis because the levels of the second factor (in this case cropping sequence before planting maize) are not common to all treatments. The Student Newman-Keuls test was performed to compare differences in means among treatments and also among land use types. All significance levels were set at $P < 0.05$.

Results

Farmers' perception and knowledge concerning the role of NPK-SB and urea fertiliser and their residual effects

There is no specific local name to designate the NPK-SB and urea fertiliser apart from their commercial names. Farmers compared NPK-SB to *wassa wassa*, a local couscous made with yam chips because of its ashy and reddish colour and granule form. They stated that the NPK-SB contributes to cotton growth and that it allows the cotton plant to develop a lot of branches. Most of the farmers did not know that NPK-SB is a compound fertiliser containing nitrogen, phosphorus, potassium, sulphur and boron. Quoting the words of one farmer: "W*e saw most of the time on the fertiliser bag NPKSB 14-23-14-5-1 but we did not know the specific meaning of that formula and the extension agent never explained to us the meaning*." According to farmers, NPK-SB fertiliser after application to cotton remains in the soil and a succeeding food crop may benefit from it.

Farmers compared the urea with salt because of its white colour and its hygroscopic characteristics (urea dissolves rapidly compared with NPK-SB). Farmers also claimed that cotton plants become scorched when the urea is applied very close to the plant roots. According to farmers, this fertiliser contributes to plant health if rain is plentiful, even when cotton and maize plants already have dark green leaves. It also contributes to cotton capsule formation and therefore to yield enhancement. Finally, farmers' were aware that the mineral fertilisers contribute to the development of weeds in both cotton and subsequent maize fields compared to a non-fertilised field.

Effect of land use types and fertiliser application practices on soil chemical properties

Apart from P-Bray 1, soil chemical properties before planting the maize crop were significantly ($0.01 < P < 0.05$) affected by the land use types (Table 2a). Soil pH was significantly ($P < 0.05$) higher in the egusi melon-cotton-cotton field than that of cotton-maize-cotton field (Table 2b). Total N was significantly ($P < 0.05$) higher in the cassava-maize-cotton and cotton-maize-

Table 2a. Nested analysis of variance (F-values) of soil chemical properties before planting the subsequent maize crop regarding fertiliser treatments (FAP) for cotton crop and land use types (LUT). Figures in parentheses are probability of F-values. (Symbols for significance levels: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$; ns not significant).

Source of variation	df	pH (water)	Total N	P-Bray 1	Exch. K^{+}	NH_4^{+}-N	NO_3^{-}-N
LUT	3	4.15^{*}	5.23^{*}	2.79 ns	19.62^{**}	10.46^{**}	11.92^{**}
		(0.0476)	(0.0273)	(0.1095)	(0.0005)	(0.0038)	(0.0025)
FAP (LUT)	8	1.68 ns	1.56 ns	4.59^{**}	2.14	1.45 ns	1.42 ns
		(0.1377)	(0.1708)	(0.0006)	(0.0568)	(0.2087)	(0.2213)
CV (%)	36	3.36	15.78	25.00	22.70	19.29	16.37

Table 2b. Mean values (± standard error, n = 4 within fertiliser treatments and n = 12 within land use types) of soil (0-20 cm) chemical properties before planting the subsequent maize crop regarding fertiliser treatments for cotton crop and land use types. Within column, means followed by letters with the same characters are not significantly different ($P > 0.05$) (Newman-Keuls test).

Land use types	Fertiliser treatments	pH (water)	Total N ($g\ kg^{-1}$)	P-Bray 1 ($mg\ kg^{-1}$)	Exch. K^{+} ($cmol\ kg^{-1}$)	NH_4^{+}-N ($mg\ kg^{-1}$)	NO_3^{-}-N ($mg\ kg^{-1}$)
Egusi-cotton-cotton	R	6.7 ± 0.1	1.6 ± 0.1	14.5 ± 1.9	0.2 ± 0.0	7.0 ± 0.9	7.4 ± 0.3
	M	6.7 ± 0.1	1.4 ± 0.1	10.3 ± 1.1	0.2 ± 0.0	6.5 ± 0.7	6.1 ± 0.0
	Red	6.8 ± 0.2	1.9 ± 0.2	12.1 ± 2.1	0.2 ± 0.0	6.9 ± 0.3	6.6 ± 0.6
	Mean	6.7 ± 0.1 A	1.6 ± 1.0 B	12.3 ± 1.0	0.2 ± 0.0 B	6.8 ± 0.4 A	6.7 ± 0.2 A
Cotton-maize-cotton	R	6.3 ± 0.0	2.0 ± 0.0	24.0 ± 1.4	0.4 ± 0.0	10.1 ± 0.8	8.1 ± 0.8
	M	6.4 ± 0.1	2.2 ± 0.2	22.6 ± 2.2	0.5 ± 0.0	7.8 ± 0.3	8.0 ± 0.7
	Red	6.4 ± 0.0	2.4 ± 0.2	21.7 ± 2.2	0.5 ± 0.0	7.4 ± 1.1	6.6 ± 0.4
	Mean	6.3 ± 0.0 B	2.2 ± 0.1 A	22.8 ± 1.1	0.4 ± 0.0 A	8.4 ± 0.6 A	7.6 ± 0.4 A
Cassava-maize-cotton	R	6.4 ± 0.1	2.2 ± 0.1	21.0 ± 4.5	0.2 ± 0.0	7.6 ± 0.5	7.8 ± 0.9
	M	6.7 ± 0.2	2.1 ± 0.2	25.0 ± 4.2	0.2 ± 0.0	6.6 ± 0.7	7.0 ± 0.3
	Red	6.6 ± 0.1	1.9 ± 0.1	18.3 ± 2.9	0.2 ± 0.0	7.0 ± 0.4	7.0 ± 0.3
	Mean	6.6 ± 0.1 AB	2.1 ± 0.1 A	21.4 ± 2.2	0.2 ± 0.0 B	7.0 ± 0.3 A	7.2 ± 0.3 A
Groundnut-maize-cotton	R	6.7 ± 0.2	2.1 ± 0.3	33.7 ± 1.5 a	0.3 ± 0.0	4.9 ± 0.3	4.1 ± 0.4
	M	6.3 ± 0.1	1.9 ± 0.1	21.7 ± 0.8 b	0.3 ± 0.0	4.8 ± 0.4	4.8 ± 0.7
	Red	6.4 ± 0.1	1.9 ± 0.1	14.2 ± 2.1 c	0.2 ± 0.0	4.8 ± 0.7	5.2 ± 0.4
	Mean	6.5 ± 0.1 AB	2.0 ± 0.1 AB	23.2 ± 2.6	0.3 ± 0.0 B	4.8 ± 0.3 B	4.7 ± 0.3 B

R = Recommended fertiliser application practices; M = NPK-SB mixed with urea practice;
Red. = Reduction of NPK-SB dose plus urea (split as recommended practice).

cotton fields compared to the egusi melon-cotton-cotton field. Exchangeable K^+ in the cotton-maize-cotton field was significantly ($P < 0.01$) higher compared to that of groundnut-maize-cotton, cassava-maize-cotton and egusi melon-cotton-cotton fields. Both NH_4-N and NO_3-N concentrations in the soil were significantly ($P < 0.01$) lower in the groundnut-maize-cotton field than in the other land use types.

Fertiliser treatments had a significant effect ($P < 0.01$) only on P-Bray 1 (Table 2a). P-Bray 1 differed significantly ($P < 0.01$) only in the groundnut-maize-cotton land use field. Plots of the recommended practice showed highest and those of the reduced NPK-SB dose lowest P-Bray 1. In the other fields the reduction of the NPK-SB dose practice showed somewhat lower soil P, but differences were not significant.

Effects of land use types and fertiliser treatments on cotton yields

The cotton fibre plus seed yield and stalk mass were significantly ($P < 0.05$ and $P < 0.01$ respectively) affected by land use types. Fertiliser treatments did not affect the cotton fibre and seed yield and stalk mass (Table 3). The cotton fibre and seed yield and stalk mass regarding the four land use types and fertiliser treatments are presented in Fig. 1. The overall means regarding the land use types indicated that cotton fibre and seed mass in the egusi melon-cotton-cotton field was almost 1.5 times higher than that in the cassava-maize-cotton field.

Cotton fibre and seed mass ranged between 1.2 to 2.0 t DM ha^{-1} for all three fertiliser treatments. Stalk mass followed a similar trend. The quantity of stalk ranged between 3.1 to 5.4 t DM ha^{-1}, 3.1 to 5.7 t DM ha^{-1} and 4.0 to 6.2 t DM ha^{-1} for the recommended, NPK-SB mixed with urea and reduction of NPK-SB practices respectively. Average stalk mass in the groundnut-maize-cotton field was significantly ($P < 0.01$) lower than in the other fields.

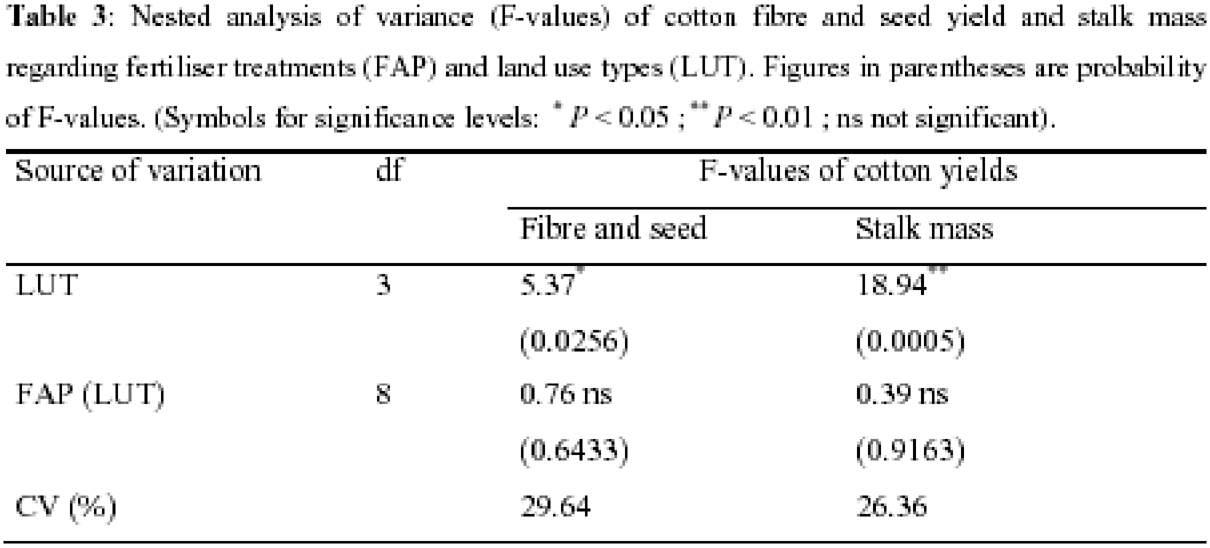
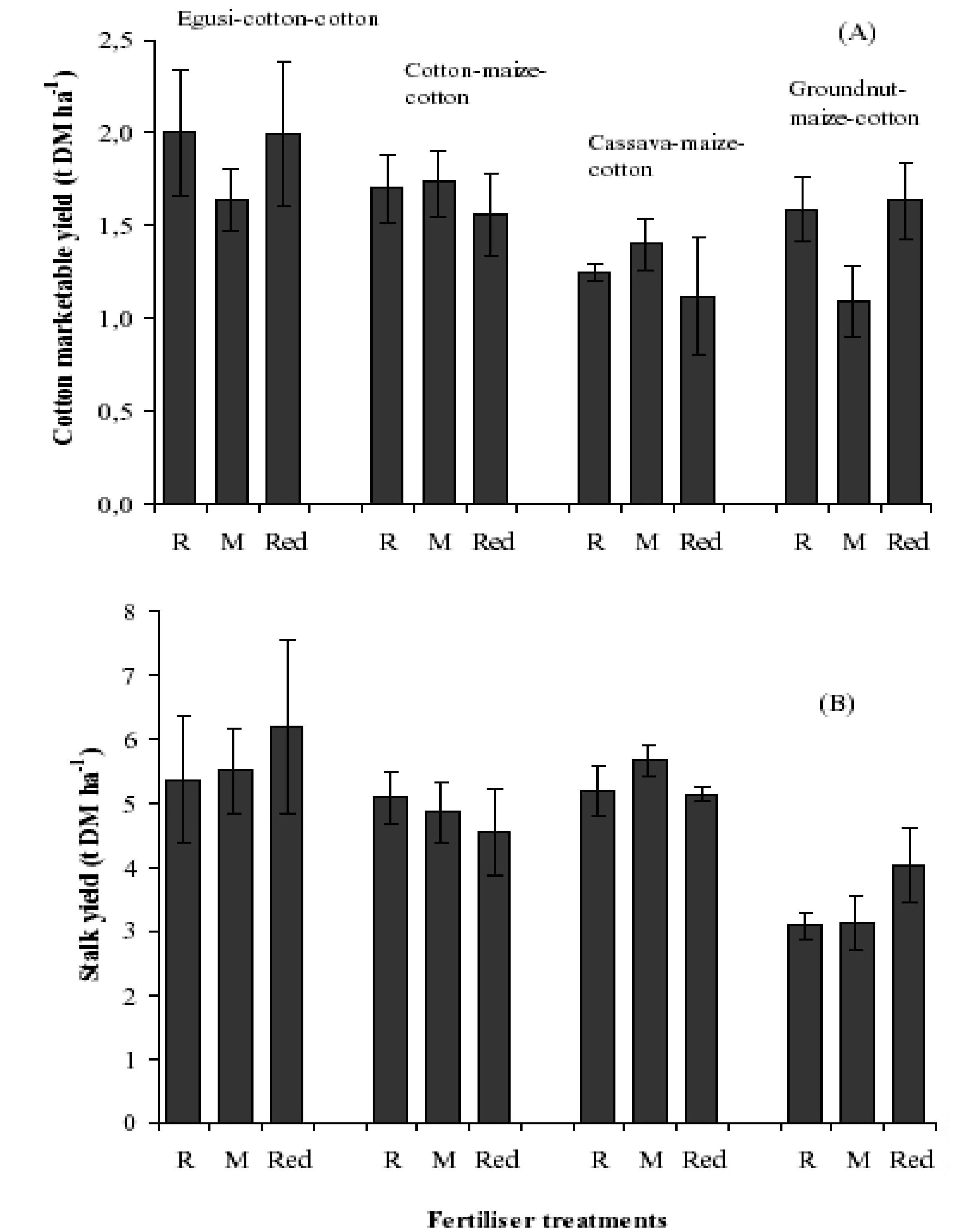


Table 3: Nested analysis of variance (F-values) of cotton fibre and seed yield and stalk mass regarding fertiliser treatments (FAP) and land use types (LUT). Figures in parentheses are probability of F-values. (Symbols for significance levels: $^{*}P < 0.05$; $^{**}P < 0.01$; ns not significant).

Source of variation	df	F-values of cotton yields	
		Fibre and seed	Stalk mass
LUT	3	5.37^{*}	18.94^{**}
		(0.0256)	(0.0005)
FAP (LUT)	8	0.76 ns	0.39 ns
		(0.6433)	(0.9163)
CV (%)		29.64	26.36



R = Recommended fertiliser application practices; M = NPK-SB mixed with urea practice;

Red. = Reduction of NPK-SB dose plus urea (split as recommended practice).

Figure 1. (A) Cotton fibre and seed and (B) stalk yields regarding fertiliser treatments and land use types. Vertical bars denote standard errors.

Effect of land use types and fertiliser treatments on the succeeding maize crop and nutrient uptake

Table 4a presents the results of the nested ANOVA of subsequent maize regarding land use types and fertiliser treatments. Maize grain and stover yields were significantly ($P < 0.0001$) affected by land use types whereas fertiliser treatments did not have a significant ($P > 0.05$) effect on yield. Cob length was significantly ($P < 0.0001$) lower in the groundnut-maize-cotton field than in the other three fields (Table 4b). Cob width in the egusi melon-cotton-cotton field was significantly ($P < 0.0001$) higher than that in the other fields, of which the groundnut-maize-cotton system was even lower than the two other systems (cotton-maize-cotton and cassava-maize-cotton).

Fig. 2 shows the mean values of the subsequent maize grain and stover yields regarding fertiliser treatment and land use type. Grain yields ranged between 0.3 to 2.5 t DM ha^{-1} for all fertiliser treatments. Grain yields were highest in the egusi-cotton-cotton field (2.3 t DM ha^{-1}) and lowest in the groundnut-maize-cotton field (0.3 t DM ha^{-1}), consistent with data on cob length and cob width, and data on NH_4-N and NO_3-N availability at the start of the maize growth, which all showed lowest values in the groundnut-maize-cotton field. Maize stover showed the same pattern of being highest in the egusi-cotton-cotton field and lowest in the groundnut-maize-cotton field.

Table 5a presents the results of the nested ANOVA for grain and stover nutrient concentration and the total nutrient uptake. Again, land use type significantly affected nutrient concentrations of maize grain (N, P, K) and stover (P, K) and total nutrient uptake (N, P, K). Fertiliser treatment was never a significant source of variation. The implication is that farmers make a rational choice by mixing or reducing the amount of fertiliser, because the recommended practice is not more profitable for the farmers than the alternatives. Nutrient analysis of the grains (Table 5b) indicated that the nitrogen concentration in the groundnut-maize-cotton field was significantly lower than that of the other fields, while phosphorus concentration was significantly lower in the egusi-cotton-maize field than in the other fields, and potassium concentration was significantly higher in the cassava-maize-cotton field than in the others. Total nitrogen uptake was highest in the egusi-cotton-cotton field and lowest in the groundnut-maize-cotton field, consistent with data on grain yield. Total phosphorus uptake and potassium were also lowest in the groundnut-maize-cotton field. The N : P ratios of nutrients taken up indicated that P was relatively more limiting in the egusi-cotton-cotton field (N : P = 7.6), whereas N was relatively more limiting in the cassava-maize-cotton field (N : P = 4.3).

Table 4a. Nested analysis of variance (F-values) of cob size, maize grain and stover yields regarding fertiliser treatments (FAP) and land use types (LUT). Figures in parentheses are probability of F-values. (Symbols for significance levels: *** $P < 0.0001$; ns not significant).

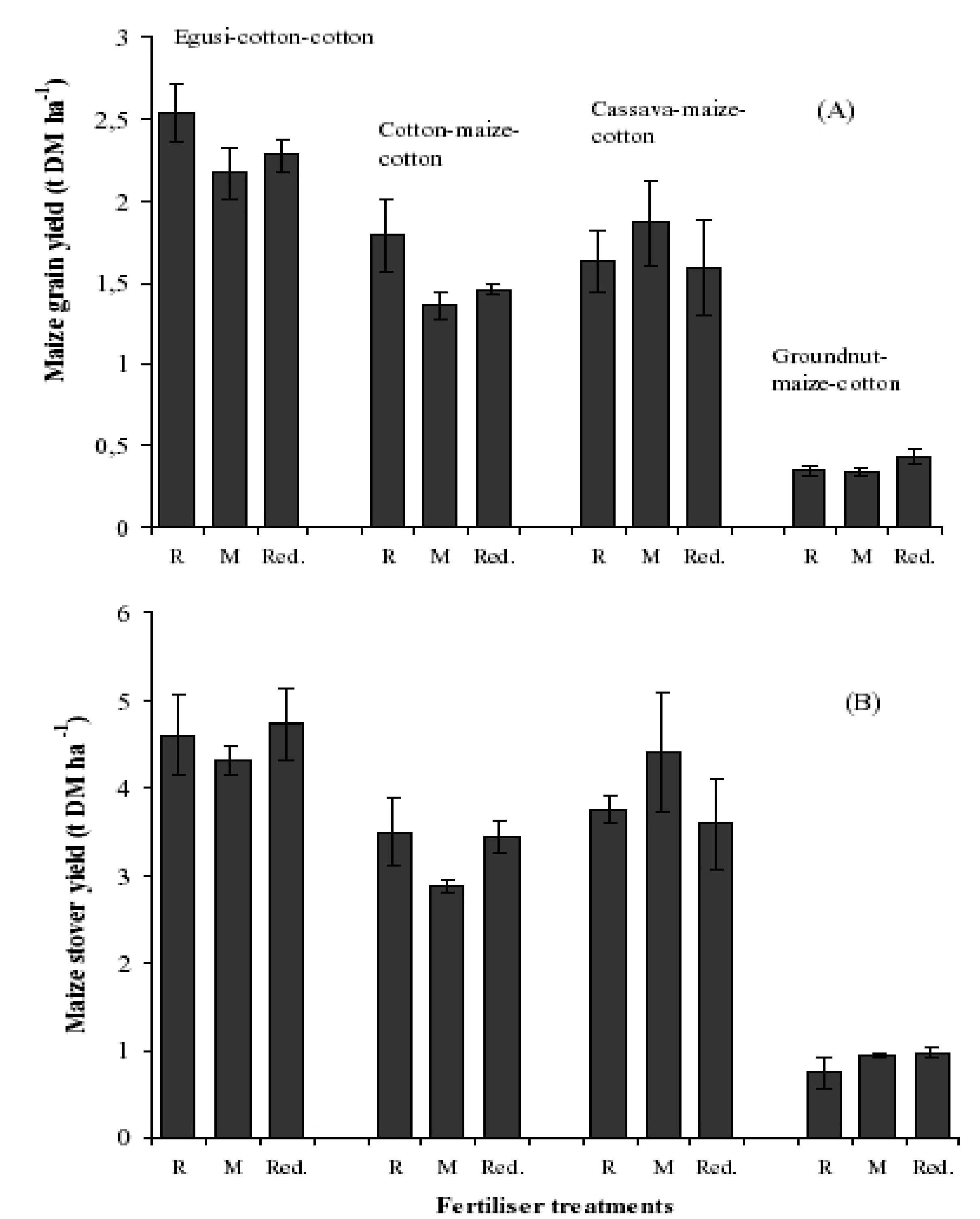
Source of variation	df	F-value of cob size		F-values of maize yields	
		Length	Width	Grain	Stover
LUT	3	72.20***	128.76***	70.61***	86.63***
		(<0.0001)	(<0.0001)	(< 0.0001)	(<0.0001)
FAP (LUT)	8	0.70 ns	0.37 ns	1.09 ns	0.77 ns
		(0.6859)	(0.9321)	(0.3930)	(0.6341)
CV (%)		10.55	4.83	21.65	21.66

Table 4b. Mean values (± standard error, n = 4 within the fertiliser treatments and n = 12 within land use types) of the subsequent maize cob size (length and width) regarding fertiliser treatments for cotton crop and land use types. Within column, means followed by letters with the same characters are not significantly different ($P > 0.05$) (Newman-Keuls test).

Land use types	Fertiliser treatments	Cob length (cm)	Cob width (cm)
Egusi-cotton-cotton	R	16.2 ± 0.6	16.6 ± 0.3
	M	15.3 ± 0.6	16.4 ± 0.4
	Red	16.5 ± 1.0	16.5 ± 0.2
	Mean	16.0 ± 0.4 A	16.5 ± 0.2 A
Cotton-maize-cotton	R	15.3 ± 0.3	15.9 ± 0.3
	M	15.0 ± 0.9	15.2 ± 0.2
	Red	15.8 ± 0.3	15.5 ± 0.1
	Mean	15.4 ± 0.3 A	15.5 ± 0.1 B
Cassava-maize-cotton	R	15.3 ± 1.2	15.8 ± 0.3
	M	15.2 ± 0.9	15.6 ± 0.6
	Red	14.4 ± 0.6	15.6 ± 0.5
	Mean	15.0 ± 0.5 A	15.7 ± 0.2 B
Groundnut-maize-cotton	R	8.5 ± 0.7	13.2 ± 0.5
	M	10.1 ± 0.8	13.3 ± 0.6
	Red	9.7 ± 0.3	12.8 ± 0.1
	Mean	9.4 ± 0.4 B	13.1 ± 0.2 C

R = Recommended fertiliser application practices; M = NPK-SB mixed with urea practice;

Red. = Reduction of NPK-SB dose plus urea (split as recommended practice).



R = Recommended fertiliser application practices; M = NPK-SB mixed with urea practice;

Red. = Reduction of NPK-SB dose plus urea (split as recommended practice).

Figure 2. (A) Subsequent maize grain and (B) stover yields regarding fertiliser treatments, land use types. Vertical bars denote standard errors.

Table 5a: Nested analysis of variance (F-values) of N, P and K concentration in the subsequent maize grain and stover and N, P and K uptake regarding fertiliser treatments (FAP) and land use types (LUT). Figures in parentheses are probability of F-values. (Symbols for significance levels : † $P < 0.1$ * $P < 0.05$; ** $P < 0.01$; *** $P < 0.0001$; ns not significant)

Source of variation	df	F-values of grain nutrient concentration			F-values of stover nutrient concentration			F-values of total nutrient uptake		
		N	P	K	N	P	K	N	P	K
LUT	3	38.46^{***}	12.32^{**}	16.03^{**}	$3.35^{\dagger}$	6.31^{*}	9.29^{**}	72.84^{***}	17.77^{**}	47.98^{***}
		(<0.0001)	(0.0023)	(0.0010)	(0.0761)	(0.0167)	(0.0055)	(<0.0001)	(0.0007)	(<0.0001)
FAP (LUT)	8	0.54 ns	0.72 ns	0.38 ns	$2.08^{\dagger}$	1.79	1.12 ns	0.77 ns	1.59 ns	0.73 ns
		(0.8213)	(0.6752)	(0.9247)	(0.0642)	(0.1115)	(0.3707)	(0.6310)	(0.1610)	(0.6632)
CV (%)		10.87	22.32	18.15	14.52	28.89	16.35	24.30	32.07	28.58

Table 5b: Mean values (± standard error, n = 4 within fertiliser treatments and n = 12 within land use types) of N, P and K concentration in the subsequent maize grain and stover and N, P and K uptake regarding fertiliser treatments, land use types. Within column, means followed by the same letter are not significantly different ($P > 0.05$) (Newman-Keuls test).

Land use types	Fertiliser treatments	Grain nutrient concentration (g kg^{-1})			Stover nutrient concentration (g kg^{-1})			Total nutrient uptake (kg ha^{-1})		
		N	P	K	N	P	K	N	P	K
Egusi-cotton-cotton	R	17.6 ± 0.3	2.1 ± 0.3	2.9 ± 0.1	7.0 ± 1.1	0.9 ± 0.3	5.9 ± 0.5	77.6 ± 9.7	9.5 ± 0.7	35.2 ± 5.2
	M	17.2 ± 0.7	3.1 ± 0.8	3.4 ± 0.4	7.7 ± 0.3	0.5 ± 0.0	5.1 ± 0.7	70.4 ± 2.7	8.7 ± 1.2	29.8 ± 3.8
	Red	17.3 ± 0.4	3.0 ± 0.5	3.2 ± 0.2	8.6 ± 0.8	1.0 ± 0.1	5.6 ± 0.5	79.2 ± 2.3	11.4 ± 1.0	33.3 ± 2.2
	Mean	17.4 ± 0.3 A	2.7 ±0.3 B	3.2 ±0.2 B	7.7 ±0.4	0.8 ±0.1 B	5.5 ±0.3 B	75.7 ±3.3 A	9.9 ±0.6 A	32.8 ±2.2 A
Cotton-maize-cotton	R	15.4 ± 0.9	4.2 ± 0.3	2.9± 0.2	8.1 ± 0.7	1.4 ± 0.1	7.1 ± 0.5	56.6 ± 8.2	12.7 ± 1.9	29.5 ± 2.2
	M	17.3 ± 0.7	3.7 ± 0.4	3.1 ± 0.3	7.3 ± 0.2	0.9 ± 0.2	8.0 ± 0.6	44.7 ± 2.5	7.6 ± 0.8	27.3 ± 2.2
	Red	17.3 ± 1.1	3.8 ± 0.3	2.8 ± 0.2	9.3 ± 0.4	1.0 ± 0.3	9.0 ± 0.9	57.0 ± 1.2	9.0 ± 1.3	35.4 ± 4.9
	Mean	16.7 ±0.5 A	3.9 ±0.2 A	2.9 ±0.1 B	8.2 ±0.3	1.1 ±0.1AB	8.0 ±0.4 A	52.7 ±3.1 B	9.8 ±1.0 A	30.7 ±2.0 A
Cassava-maize-cotton	R	15.3 ± 1.2	4.3 ± 0.3	4.0 ± 0.2	9.4 ± 0.3	1.6 ± 0.2	7.8 ± 0.4	60.9 ± 4.9	13.1 ± 1.8	36.0 ± 2.2
	M	15.1 ± 1.4	4.6 ± 0.5	3.8 ± 0.3	7.8 ± 0.1	1.5 ± 0.1	7.4 ± 0.5	63.2 ± 11.0	15.6 ± 3.1	40.3 ± 7.4
	Red	14.7 ± 0.9	4.4 ± 0.3	3.9 ± 0.4	7.8 ± 1.1	1.3 ± 0.2	7.1 ± 0.5	51.5 ± 10.6	11.6 ± 1.5	31.9 ± 5.7
	Mean	15.0 ±0.6 B	4.5 ±0.2 A	3.9 ±0.2 A	8.3 ±0.4	1.5 ±0.1 A	7.5 ±0.3 A	58.5 ±5.1 B	13.5 ±1.3 A	36.1 ±3.1 A
Groundnut-maize-cotton	R	12.7 ± 0.5	3.7 ± 0.2	3.4 ± 0.4	9.5 ± 0.4	1.3 ± 0.2	7.6 ± 0.7	11.5 ± 2.0	2.3 ± 0.4	6.8 ± 1.4
	M	12.6 ± 0.8	4.2 ± 0.5	5.0 ± 0.3	9.3 ± 0.8	1.7 ± 0.1	7.2 ± 0.5	13.0 ± 0.6	3.1 ± 0.3	7.8 ± 0.5
	Red	12.0 ± 0.4	3.5 ± 0.3	3.2 ± 0.3	10.9 ± 0.1	1.7 ± 0.2	6.5 ± 0.3	15.8 ± 1.1	3.1 ± 0.5	7.6 ± 0.5
	Mean	12.4 ±0.3 C	3.8 ±0.2 A	3.3 ±0.2 B	9.9 ±0.3	1.6 ±0.1 A	7.1 ±0.3 A	13.4 ±0.9 C	2.9 ±0.2 B	7.4 ±0.5 B

R = Recommended fertiliser application practices; M = NPK-SB mixed with urea practice; Red. = Reduction of NPK-SB dose plus urea (split as recommended practice).

Discussion and Conclusion

Farmers' knowledge of deficiency symptoms and workings of fertilisers

Farmers' knowledge, as defined by Van der Bliek and Van Veldhuizen (1993), refers to ideas, experiences, practices, information generated locally, or if generated elsewhere, transformed locally and incorporated in local ways of understanding. It incorporates local technologies but also cultural, social and economic aspects. Through cultivating cotton (a crop supplied with fertiliser inputs) farmers have become aware of both direct and residual effects of fertilisers. Knowledge of residual effects arises through cultivating maize after cotton. Quoting the words of one farmer: "W*hen fertiliser, especially NPK-SB, is applied, cotton plants do not use the entire amount and part is still in the soil. For a better utilisation of the remaining fertiliser, we prefer to cultivate food crops, especially maize, which is a nutrient-demanding crop"*. This crop rotation system was also mentioned by Benjaminsen *et al*. (2006) in the Malian cotton zone, and it can be regarded as a strategy developed by local farmers to sustain grain production and improve food self-sufficiency. Farmers are aware of the beneficial effect of prior fertilisers on cotton to cereal crops. Nevertheless, their knowledge on carry-over effects of fertiliser in the soil is still limited. During the different learning group discussions it came out that processes such as leaching of nitrate and K were unknown. Farmers did not make a difference between residual effects of NPK-SB and that of urea. Learning group meetings provided an interactive forum where the researcher and farmers exchanged knowledge and learnt from each other. The role and pathway of each nutrient contained in both NPK-SB and urea was explained to farmers by the researcher.

In the field, maize plants with leaves presenting purple reddish colours (an indicator for P deficiency) were observed. According to the farmers, leaf discolourations are signs that appear where soils are "weak" or "tired". The SLG members recognised that plant leaves presenting this discolouration are not healthy, and they attributed the sign to "food" (nutrient) deficiencies. Farmers, in this instance, seem to be on the verge of a valid explanation. Cropping systems with egusi melon may induce greater P-deficiency than cropping systems with cassava. The role that cassava plays in ameliorating P-deficiency is possibly to be explained through mycorrhizal carry-over effects (*cf* Chapter 4). Farmers' explanations were less insightful in another case. In the groundnut-maize-cotton system maize leaves sometimes presented yellowish colours (a probable indicator for N deficiency). Farmers attributed this sign to drought, because they considered that the plants were healthy. Wilted leaves do eventually become yellow, and by assimilating yellow leaves to drought and not to N deficiency farmers could miss the correct mechanism for understanding the under-performance of maize. In other words, not all signs point farmers in the direction of a correct understanding of mechanism. SLG learning groups proved to be a forum in which some aspects of farmer knowledge concerning soil fertility could be given recognition and other aspects challenged.

Technology adaptation and farmers' rationality

Farmers in the centre of Benin have diverse soil fertility management practices (Saïdou *et al*., 2004). They have adapted the technological package accompanying cotton. Wennink *et al*. (2000) made similar observations about cotton farming systems in northern Benin. There too mineral fertiliser is applied in doses that are generally (well) below the rate recommended by the extension service. Farmers (deliberately) under-estimate the surface area in order to apply less fertiliser because it is delivered on credit, and the potential yield increase may not be worth the additional debt. Farmers also apparently think that taking more fertiliser on credit and store it, and then applying it directly on maize, does not pay off either due to the relatively low sale price of staple cereal crops or restricted local markets for staple foods. Furthermore, the fact that lowering the NPK-SB dose did not significantly affect yield in our study, shows that this strategy is perfectly rational. Next to lowering the amount of NPK-SB, farmers also prefer to mix NPK-SB and urea. Farmers' choice here is based on reduced labour for fertiliser application and reduced weeding. Farmers claimed that heavy supply of mineral fertiliser leads to an increased requirement for weeding. Finding labourers for weeding is a constraint, because labourers generally prefer ploughing to weeding. Quoting the words of a farmer from Boubouhou: *"Supplying fertiliser twice on the same field as recommended by the extension agent is a waste of time. I produce food crops and cash crops, and these fields have to be weeded in the same period. It is not easy to find labourers, especially most of the seasonal migrants prefer ploughing rather than weeding because the former (work) is better paid"*. The same claim has also been reported by Gray and Morant (2003) in south-western Burkina Faso and by Olatoundé (2005) in the centre and south Benin. These authors stated that weeds are the primary reason for farmers to leave their fields in fallow.

Apparently, farmers are guided by both instrumental and strategic rationality (Habermas, 1984; 1987), two of the three ways of being effective (Röling and Maarleveld, 1999). Instrumental rationality deals with cause and effect relationships and their instrumental manipulation through techniques in service of reaching given goals such as better time management. It aims at control over the biophysical environment based on past success. Strategic rationality assumes that one is faced with other strategic intentional actors. Various strategic intentions - *e.g.* crop diversification (*i.e.* risk minimisation through producing both food crops and cash crops during the same period), reduction of input, prevention of infestation by weeds, and finally profit maximisation -, are all key elements for innovation adoption or adaptation.

Crop rotation was observed as a local strategy of soil fertility and cropping system management (Saïdou *et al*., 2004). Crop rotations are a central component in the development of resource-conserving farming, with optimal use of crops that contribute to soil fertility and reduce pest damage (Pretty, 1995). Generally, farmers' decisions in term of crop to be grown are guided by socio-economic criteria (market prices during the prior agricultural season, labour constraints, food habits, cultural requirements, etc.) and not by the perspective of soil fertility improvement. Crops having high economic importance (*e.g.,* cotton) therefore appear frequently in the rotation sequence. Cotton also has a positive effect on the soil due to the residual effect of fertiliser. In traditional cropping systems of central Benin tuber crops, cereal crops, grain legumes, egusi melon, and cotton are rotated according to farmers' skill. Legumes in the rotation system can increase soil fertility through their nitrogen-fixing capacity. But only legumes with high biomass (*i.e.* low harvest index) are effective in terms of soil fertility improvement, while those producing high harvestable produce (*i.e.* high harvest index) tend to deplete the soil because a large amount of nitrogen fixed is removed from the system through harvesting of grains (Giller and Cadisch, 1995; Vanlauwe and Giller, 2006). Prior cassava can possibly improve succeeding crop yields either by its relatively low nutrient extraction or by its ability to form symbiotic associations with arbuscular mycorrhizal fungi (Howeler, 2002; Salami and Osonubi*,* 2002). High mycorrhizal inoculum potential at the start of the next cropping season might have major beneficial effects on P-uptake and growth of the subsequent crop (Goss and De Varennes, 2002).

Generally technology adaptation is normally preceded by farmers' experimentation. But farmer experiments may be associated with risks, and therefore only a minority of farmers regularly engage in such experimentation. However, after a new technique has been successfully tried, it could also become a feasible solution for neighbouring farmers. Technology adaptation regarding fertiliser application practices (mixing of NPK-SB and urea) is widely adopted in the home villages of migrants. Native farmers have subsequently learned from migrants. This practice is now becoming widely adopted and mixing is especially important when the fertiliser is delivered very late. In fact, the input, managed by the farmers' organisation in collaboration with input marketing companies, is often delivered to farmers after the recommended period of application has expired. The novel practice of mixing NPK-SB and urea does neither adversely affect cotton yield (by comparison with standard recommendations) and subsequent maize yield.

Agronomic effectiveness

Not all nutrients are taken up by the growing crop. Those remaining may either stay in the soil and result in carry-over effects to the next crop or be lost by leaching or run off caused by rainfall. The relative importance of nutrient losses depends on the relationships between crop growth, nutrient dynamics, and water dynamics. Fertiliser splitting, as recommended by the extension service, is a strategy to reduce nutrient loss, compared to farmers' practice to mix NPK-SB and urea. In both cases, fertiliser N can be lost to the atmosphere through ammonia volatilisation, especially when the fertiliser holes are not closed. Nitrate-N is also subject to leaching. The risk for nitrate leaching is much more important in areas with higher rainfall intensities and lower water storage capacity (sandy texture). Timing of N application can be agronomically relevant in this environment. Both N fractions (NH_4-N and NO_3-N) in the soil before planting maize were not different regarding the fertiliser application practices. We expected a significant difference between the splitting practice and the mixing practice, but such an effect was neither discovered in cotton or in maize yield.

Apart from the groundnut-maize-cotton field, the subsequent maize grain yields were reasonably good because they were rather close to the maximum yield (4 to 6 t ha^{-1}) that the DMR cultivars can reach on-station under controlled conditions. Maize in the groundnut-maize-cotton had small and poorly filled cobs, and was short. This low performance was possibly the result of inadequate management by the farmer. With the exception of the groundnut-maize-cotton field, grain yields were higher than 1.3 t ha^{-1} of grain found in extensive cassava cultivars odongbo rotated with maize with a minimum supply of NPK-SB (100 kg ha^{-1}) (*cf* Chapter 4). These latter results were affected by drought because in that study, subsequent maize was sown late in the course of the cropping period whereas in our present study maize was sown at the commencement of the rainy season. Our results corroborate results of a long-term experiment carried out from 1995 to 1999 (CRA-CF, 2000) on cotton-maize rotation by the Benin cotton research institute in Aplahoué (South-East Benin) on ferruginous soil. It was found there that cotton yield ranged between 0.24 and 2.15 t. ha^{-1} and subsequent maize grain yield ranged between 0.38 and 2.28 t ha^{-1}.

The overall average proportions N:P:K were 7.6:1:3.3, 5.4:1:3.1, 4.3:1:2.7 and 4.6:1:2.6 for egusi melon-cotton-cotton, cotton-maize-cotton, cassava-maize-cotton and groundnut-maize-cotton fields respectively which are comparable to the 5.1:1:3.6 ratio found by Saïdou *et al*. (2003) for local tall maize cultivars on ferralitic soil in southern Benin. Janssen *et al.* (1994) indicated an optimum N:P:K ratio of 7.8:1:5 for hybrid maize. Our N:P ratios suggest either differences between local maize and hybrid maize, or conditions were N was more limiting or P was less a constraint. The low N:P ratio in the cassava-maize-cotton field is consistent with the hypothesis that the prior cassava had increased P-availability in the system (*cf* Chapter 4).

Implications for research and extension

The findings were extensively discussed in the feedback session after completing the chemical analyses in the laboratory. Farmers did not look at stover production but at grain yield. The stover was introduced in the experiment by the researcher for the assessment of nutrient balances.

The experiments made clear that in the context of technology development, its adoption and adaptation by farmers must be taken into account by researchers and extensionists. Fertiliser recommendations for cotton in Benin are made on the basis of blanket practices based on nutrient response multi-location experiments. Henceforth, researchers need to take into account the diversity in the land use system and constraints (labour, credit, availability on the market) in order to come up with rational fertiliser recommendations. It may also be necessary to assess nutrient stocks in the soil in order to make fertiliser recommendations tailored for the specific requirements of each field. It is also important to learn from farmers' practices. This can be done effectively by using an interactive approach, as shown by the present data from involving farmers in the research process. The interactive approach is especially relevant where clients of participatory research are marginalized within national political life, as is frequently the case (Amanor, 1990). The interactive approach adopted in the present case study is an example illustrating the shift from functional participation based on a contractual approach to a more collegial mode of participation (Biggs, 1989).

In order to make mineral fertiliser use more profitable to farmers, the recommendations should not focus on fertilisation as a practice in isolation but should take account of farmer management skills, seasonality, labour availability, fertiliser availability and farmers' objectives. However, to sustain balanced nutrition, measures may also be needed to improve nutrient use efficiency by promoting crop residue management, *i.e.* leaving residues as mulch or ploughing them into the soil in order to improve soil organic matter content and thereby improve the efficiency of the mineral fertiliser. As farmers' knowledge on the role of individual nutrients in mineral fertilisers is limited, it is important to develop a strategy to converge scientists' theories and farmers' ideas and practices for better nutrient management. In fact, co-operation between farmers and researchers implies that both sides should regularly and carefully listen to each other. It is a key challenge to create institutional frameworks within which this mutual listening and learning can be fostered.

Chapter 6

Collaborative research by scientists and farmers on soil fertility: evaluating a coorperative experiment

A. Saïdou

Chapter 6

Collaborative research by scientists and farmers on soil fertility: evaluating a cooperative experiment

Abstract

Farmer participatory research advocates involvement of farmers as collaborators or at least as joint decision makers in the research process. In practice, there is a lack of examples where farmers are fully involved in scientific research, *i.e.* farmers having a direct role in research methodology and experimentation. Co-research by farmers and scientists was implemented in the framework of the Convergence of Sciences (CoS) program as an approach to supporting the process of co-construction of knowledge. The purpose of this study is to examine the impact of the stakeholder learning group (SLG), in terms of two dimensions of sustainable livelihood analysis (human and social capital). The co-research was carried out in Ouoghi central and Ouoghi Gare, two villages located in the transitional agro-ecological zone of Benin. The overall approach was a difference design. The evaluation was carried out by two researchers who did not participate in the co-experimental activity. The process of evaluation comprised an exploratory phase and an in-depth survey. The research method during the exploratory phase was group discussion. Survey methods used were an open-ended questionnaire and scoring. Elements of both capitals, which are meaningful to the respondents, were first elicited. Respondents were then asked to score their perception of the 'before' and 'after' situation on a scale of 0 - 5, for each of the elements identified. The co-research was perceived as a learning environment where knowledge on land management was exchanged. The process was iterative, with an ongoing feedback which allowed an adaptation of research methodology. Farmers and researchers engaged in a critical dialogue (democratisation of science). 73% of the farmers interviewed claimed that they participated in the SLG in order to improve their knowledge. The co-research activities have improved both human capital (farmers' individual knowledge and capacity building) and social capital (group dynamics, space for innovation, interaction, negotiation skills, improvement of cropping practice, improvement of social relationships, and information sharing). Farmers' knowledge on the separate roles of N, P and K nutrients and of mycorhizal associations has been greatly improved. The co-research has enriched the participatory approach by promoting co-construction of knowledge.

Keywords: Co-research, social capital, human capital, co-construction of knowledge, democratisation of science, Benin

Introduction

Scientific research has not been very efficient in answering the need to improve production on a sustainable basis. Some suggest this is due to a narrow professional vision (Lee, 2002). Rich sources of knowledge accumulated within farming communities have too long been neglected. More attention should be paid to farmers' knowledge and the rationales they use to decide on adoption or rejection of innovations. To integrate farmers' knowledge and to respond more efficiently to farmers' needs, participatory research has become widely applied (Tripp, 2006). This approach has been proposed as an alternative for an unsuccessful research approach based on a linear view of the innovation process, generally labelled transfer of technology (ToT) (Rogers, 1995; Douthwaite *et al*., 2003). It seems well established that the ToT approach is deficient in improving the well-being of resource-poor farmers (Clark, 1995; Douthwaite, 2002). The linear view of science does not model the complexity and the diversity of farming systems. In the ToT model, the research methods are largely controlled by scientists with little reference to farmer feedback during the course of research (Douthwaite *et al*., 2003). In the context of agriculture the alternative participatory approach recognises multiple sources of innovation (Röling, 2003 Douthwaite *et al*., 2001).

Farmer participatory research (with more user-oriented, flexible methods and a different, wider set of assumptions about who contributes to research) has received increased attention and recognition since the 'Farmer First' debate (Chambers *et al*., 1989) and participatory technology development concepts (Jiggins and De Zeeuw, 1992) were first introduced in the late 1980s. Acceptance of the important role that farmers can play, if given a chance, in agricultural research, development and extension has grown considerably. In approaches such as on-farm and farming systems research, farmers are often considered as research subjects or passive components of the system under investigation (Van de Fliert and Braun, 1999), while the participatory research approach advocates involvement of farmers as collaborators, or at least as joint decision makers, at all stages of the process. This can be seen as a new approach to doing science for development. Research for development requires a willingness to engage with non-professionally generated scientific knowledge and a preparedness to engage in discussion on an equal basis with stakeholders (democratisation of science). In fact, joint learning processes empower and challenge both researchers and farmers to extend their knowledge and action into new areas (Hagmann *et al*., 1999). This is particularly important for the understanding of the complexity of local soil fertility management technologies. Of particular concern is whether this type of participatory research can generate widely applicable methods, or whether results will be site-specific and limited in impact.

The work described here proceeds under the assumption that for research and development to have greater impact on smallholder farmers in developing countries there is a need to develop active participatory approaches to 'democratised' science. It should be clarified that this is a third way between professionalised positivistic science on the one hand, and the broader reaches of participation on the other. Some proponents of participation are idealists and cultural determinists, influenced by the powerful turn in the social sciences at the end of the 20th century towards humanistic understanding (*cf.* Kuper, 2001). Here, however, the aim is to develop a realist account (*cf.* Pawson and Tilley, 1997) of farmer knowledge, in which a distinction is maintained between objectively grounded knowledge and opinion or belief.

In practice, there is a lack of examples where farmers are fully involved in scientific research under realist assumptions, *i.e.* farmers having a direct role in research methodology and experiment designed to uncover causal mechanisms. Co-research by stakeholder learning group (SLG – more accurately described as stakeholder research and learning group) and scientists was implemented in the framework of the Convergence of Sciences (CoS) program (Röling *et al*., 2004; Hounkonnou *et al*., 2006) as a participatory approach supporting 'co-construction of knowledge' for enhancing farmers' empowerment and adaptive capacity. The purpose of this study is to examine the impact of the co-research in terms of two dimensions (human and social capital). Human capital is widely recognised by economists and others as the product of investment in the capacity of the individual, *e.g.* expenditure on education. Social capital will be used here as short-hand for the kind of investment in cooperative scientific capacity the CoS project undertakes of sustainable livelihood analysis as perceived farmers since they attended SLG. The study presents results of a self-evaluation by farmers, facilitated and moderated by two independent social scientists, of the learning and co-construction of knowledge processes in relation with soil fertility technology development. The ultimate aim of the study is to come up with 'better science' to contribute to improving farmers' cropping and land management practices.

Research-extension-farmers linkage and innovation process in Benin: strengths and weaknesses

As in most of the developing countries, the innovation process in Benin has evolved from the ToT approach to farmer participatory research. The research and development (R&D) team serves as link between formal research and farmers. The roles of team members consist in testing through on-farm experiment in farmer conditions improved technologies worked out in the research station under controlled conditions. The shift of emphasis towards the realities of farming and of farm families has progressed under various labels or banners, including farming systems research (FSR), Rapid Rural Appraisal (RRA), farmer participatory research (FPR) and *Approche Participative Niveau Village* (APNV)(Nouatin, 2003). All of these approaches aim to get closer to the farming realities, but do not always involve farmers to a major degree. The work is often 'researcher-driven' and generates insights only within the researcher's categories of thought. Ownership of knowledge by farmers through their participation in technology development and adaptation is lacking with the R&D in Benin, which in part explains the weak motivation of farmers to adopt improved technologies. Until recently, in order to improve farmer involvement in the research process, at each regional agricultural research centre (CRRA), the *Comité Régional de Recherche Développement* (CRRD) was institutionalised. This forum meets once a year and comprises all actors interested in agricultural research (farmers, researchers, traders, NGOs, farmer organisations, university and development projects). In this forum, the main results of experiments carried out by researchers are presented and research programs for the coming cropping season are discussed. As a prelude to the CRRD meeting, the researchers discuss in a feedback session in the village the main results of the experiment. Farmer points of view are supposed to be taken into account and presented at the CRRD forum, but this aspect is often neglected. The following step before a research result is introduced to extension is to organise a scientific workshop (*atelier scientifique)* comprising only researchers from the university and the research institute. Farmers are not represented because this technical forum discusses only the scientific significance of the research output. The dominant spirit is that of professional peer review, not farmer relevance.

Usually, the research agenda and technologies introduced are not collectively agreed upon with farmers. Indeed, in the move towards giving more prominence to farmers' agenda, the APNV approach was introduced in extension and R&D services. This newly introduced approach begins with a global (village) diagnosis in which farmers auto-analyse their situation by expressing problems they face and their expectation in term of agricultural technology to be introduced. During the diagnostic phase, farmers' expectations in term of technologies are often driven by researchers towards the available science-based technologies. In the case of soil fertility management, cover crops, agroforestry, mineral fertilisers and compost are technologies proposed. Apart from mineral fertilisers that some farmers apply to cash crops, these technological packages do not fit with their cropping system. The locally applied technologies are usually ignored. The diagnostic phase involves local NGOs, farmers' organisations at district level (UCP) and some religious structures. It does not study in-depth all of the farmers' problems; only researchable problems are tackled. Problems of infrastructure (roads, hospitals, storage facility, etc.), tenure security for migrants, and market opportunity are neglected. Involvement of key stakeholder in the research process is lacking. In this process, scientists or researchers are trained to apply a standard reductionist perspective, which narrows down a set of inter-linked problems to the point where one issue can be isolated for analysis and resolution. While this is fair enough, the problem is that there is no means to go back to the level of the original (multi-dimensional) problem faced by farmers, and to examine what contribution the proposed solution makes. Farmers have little to say in formulating the research agenda, except during the on-site diagnosis (Floquet and Mongbo, 2000). Even then, information provision was asymmetric and researchers were in a position to influence diagnostic results in order to fit in their own priorities. This brings out clearly that there is a power relationship between researchers and farmers to the farmers' disfavour (Nouatin, 2003). Such situations call for the development of new form of participatory research where farmers are able to influence the research agenda to achieve applications of new knowledge in conformity with their own livelihood objectives. In this new form of collaboration, farmers and researchers ought, ideally, to discuss on an equal basis (democratisation of science).

Methodology

Research sites

The on-farm and learning exercise were carried out in the villages of Ouoghi Central and Ouoghi Gare. The area is located in the sub-prefecture of Savè in the transitional agro-ecological zone of Benin between 7°42'and 8°45'N and 2°15'and 2°45'E. The area is characterised by a Guinea-Sudan climate with a unimodal rainfall distribution. The rainy season lasts from April to October. The annual rainfall in the last thirty years (1974-2004) is about 1100 mm (Savè weather station). The area is essentially dominated by tropical ferruginous soils (Dubroeucq, 1977) originally from Precambrian crystalline rocks (granite and gneiss). The soils are deep without laterite and often have a somewhat good inherent fertility. The total population of both villages is 3,912 inhabitants with 400 households (INSAE, 2004). The indigenous population are composed of *Tchabè* (*Yoruba* sub-group) and the herdsmen *Peulh (Fulani)*. In addition to migrants from Atacora-Donga (in the north), there has been since 1975 an influx of migrants from the Abomey Plateau (in the south). This has led to the emergence of new communities in the area formed by groups such as the *Ditammari*, *Yom* and *Waama* (from Atacora-Donga), the *Fon* (from the Abomey Plateau) and the *Idatcha* (from Dassa-Zoumè and Glazoué). Several farmer organisations are found in both villages but only the *Groupement des Producteurs de Coton* (GPC) and the women's organisation (*Groupement des Femmes*) (GF) are involved in agricultural activities. The youths are involved in off-farm activities which provide additional financial resource. *Projet de Développement de l'Elevage* (PDE III), *Projet de Développement des Racines et Tubercules* (PDRT), extension service (CeCPA), *Centre Béninois pour le Développement Economique et Social* (CEBEDES-NGO) and the Convergence of Sciences (CoS) programme are institutions intervening in both villages by providing extension services for farmers.

Research process

The evaluation was carried out from April to December 2005, *i.e.* at the end of the co-research and learning phases of the CoS intervention. To ensure greater reliability of assessment, two outsiders (with backgrounds in social science), who were not involved in the CoS project, carried out the survey. They have been involved in the writing up of the evaluation proposal and were introduced to the community by the CoS research team. The evaluation process comprised three phases: a literature review, an exploratory phase and a survey. The literature review assembled secondary data and information on the history of the participatory technology development approach in Benin. Discussion with key informants (researchers, project workers, representatives of NGOs, extensionists, and members of farmer organisations) was also organised.

The exploratory phase gave an overview of the co-research activities undertaken. The research method was mainly group discussion and recall technique. This was useful for the writing up of the checklist and the questionnaire for the survey phase. The overall approach used was a difference design (before and after the co-research activities): member of the SLG recalled what they knew before and at after the co-research activities on earthworm casting activity, nutrient cycling, soil health, plant health, role of individual nutrients in mineral fertiliser, residual effect of mineral fertiliser, and plant rooting systems.

The in-depth study was carried out from August to December 2005. A sustainable rural livelihoods framework (Scoones, 1998; DFID, 2001) was used to evaluate the relative impact of the co-research on the SLG members' livelihood. The sustainable livelihood framework was constructed around the identification of five capital assets that individuals can access, augment, and manage in the interplay of need and opportunity to sustain their livelihoods. These five kinds of capital asset are natural capital (natural resource stocks from which resource flows are derived, including land, water, biodiversity, landscape, etc.), social capital (networks, memberships in groups, relationships, and the wider institutions of society), human capital (skills, knowledge, ability to work, practices, good health, creativity etc.), physical capital (basic built infrastructure, tools and equipment), and financial capital (savings, loans, credit, remittances, pensions and other transfers). The two dimensions of capital asset investigated were human and social capital. The study did not focus on financial, physical and natural capital assets. The main reason was the short duration term (2002 to 2005) of the implementation phase of the co-research process. It seems too early yet to ask questions about formation of material capital assets through the participatory approach to soil fertility management. Farmers' livelihoods are unlikely to have changed significantly with regard to the financial, physical and natural capital assets in the short run. Therefore, when we asked farmers about their perception of the before and after situation, we expected most of the respondents to report on improvements in knowledge, memberships in groups and collective action. Only later, will it be possible to evaluate the interaction between human and social capital formation and increases in material capital assets. Participants were asked to score their perceptions of the before and after situation on the scale of 0 - 5, for each of the elements identified. This permitted the drawing of kite diagrams (spider web diagrams) showing the relative impact induced by the co-research.

The entry point was farmers' perception, *i.e.* their interpretation of processes associated with soil fertility management. The relative impacts were assessed based on the prior topics discussed in the course of the co-research activity. The survey was used to establish indications of individual farmers' sense of knowledge ownership. The participatory assessment consisted of the following steps. First each respondent was questioned to elicit the most valuable assets in each of the two capitals associated with co-research activities. An outline diagram was drawn on a poster sheet and the meanings elicited for each capital were listed on the relevant axes of the web. The questions were framed in terms of: what do you value the most, and in which form, in your livelihood, in terms of social and human capital? Secondly the respondents rated the capital stocks identified, for the baseline year (2002) and for the impact year (2005). The zero value (no stock) is found at the centre of the diagram and the value 5 at the extreme of each of the axes, corresponding to a respondent's full satisfaction regarding capital stock. Thereafter, any changes made visible between the two reference years were discussed and causes attributed to the changes were noted.

Additional data collected and data analysis

Data collected comprised group dynamics (history, evolution, composition and motivation for joining the group), the negotiation process of the research agenda and the elaboration of research proposals, role and contribution of each actor (farmers, CoS researchers and the extension agent), organisation and functioning of the group (periodicity of meetings, planning of on-farm activities, sharing information and power relationships in the group and between farmers and the researchers), perception on the relative impact of the CoS program in the village and on their cropping system (knowledge gained in term of soil fertility management, relevance of the knowledge gained, aptitude and competence in carrying out on-farm experiment, information sharing with similar group in the village, type of collaboration between the SLG members and the extension service, aptitude and competence in negotiation, etc.), and farmer perceptions concerning the co-research approach.

The process of generating and interpreting findings was participatory. The meanings listed by the respondents under each of the two capital stocks were analysed to capture farmers' livelihoods at the two reference periods. The spider web diagrams were instrumental in the visualisation of changes perceived over time and in making visible respondents' perceptions of the connections between the two forms of capital. The visualisation became a dialogic tool for reflection and discussion of the attribution of the causes of the changes recorded. Due to weak participation of women in the SLG meeting, we did not analyse the farmers' perception by gender. Women did not participate in the group discussion due to heavy workload because of involvement in trading with migrants (buying and reselling agricultural products in Savè town).

Results

Process of co-construction of knowledge by farmers and scientists

A detailed description of the research process is given by Saïdou *et al*. (2004). The process emphasises the importance of local knowledge. Farmers are considered as 'experimental researchers' because they manage their land on a day-to-day basis, observe the effects of what they do and adjust their management practices accordingly. The co-research framework brings scientific and local knowledge systems together at a single, accessible and structured focal point to support the identification and adoption of more sustainable land management practices. The co-research cycle is presented in Fig. 1. It includes the following phases: common understanding of some scientific concepts (treatment, replication, analysis of variation and variability, nutrient cycling, etc.) and farmers' theories (claims, beliefs, interpretations, and ideas), planning of action research (joint on-farm experiment and laboratory work), implementation and management of on-farm experiments and laboratory sample analysis, and continuous monitoring and evaluation (learning and adapting phase and evaluation). The process is iterative, with an ongoing feedback and problem reformulation aspect.

An environment with high existing social capital was chosen, as found in both Ouoghi villages, where farmers already are involved in several collective actions for land management (Saïdou *et al*., 2006). The negotiation of the collective research agenda setting among farmers and scientists was done in an ongoing process of group discussion of 31 participants (at the beginning of the process in February 2002). It was conducted in successive steps (Fig. 2): problem identification, prioritising researchable problems (problems related to the development of the village such as construction activities, providing drinking water, or securing a nurse or midwife for the hospital and teachers for the school were not taken into account), identification of endogenous or alternative courses of action for solving farming system problems, and selecting relevant courses of action to be studied. This process gives a room for the stakeholders to influence the scientists' research agenda (and vice versa). Additionally, farmers gain more confidence in their own knowledge and capacities as part of the democratisation of science process. This is the key to the CoS approach: by converging farmers' and scientists' knowledge and experience (through intensive and sustained interaction) 'better science' can be achieved.

The list of problems facing the farming system and strategies developed by farmers to solve them are documented in Saïdou *et al*. (2004). However, the choice to intervene in soil fertility issues was more guided by pre-analytical choices, and the highest score given to crop yield decrease (as the most important problem facing farmers) due to land degradation. Farmers cannot afford mineral fertilisers because of high costs, therefore they develop alternative land management approaches in order to achieve goals consistent with improving the livelihoods

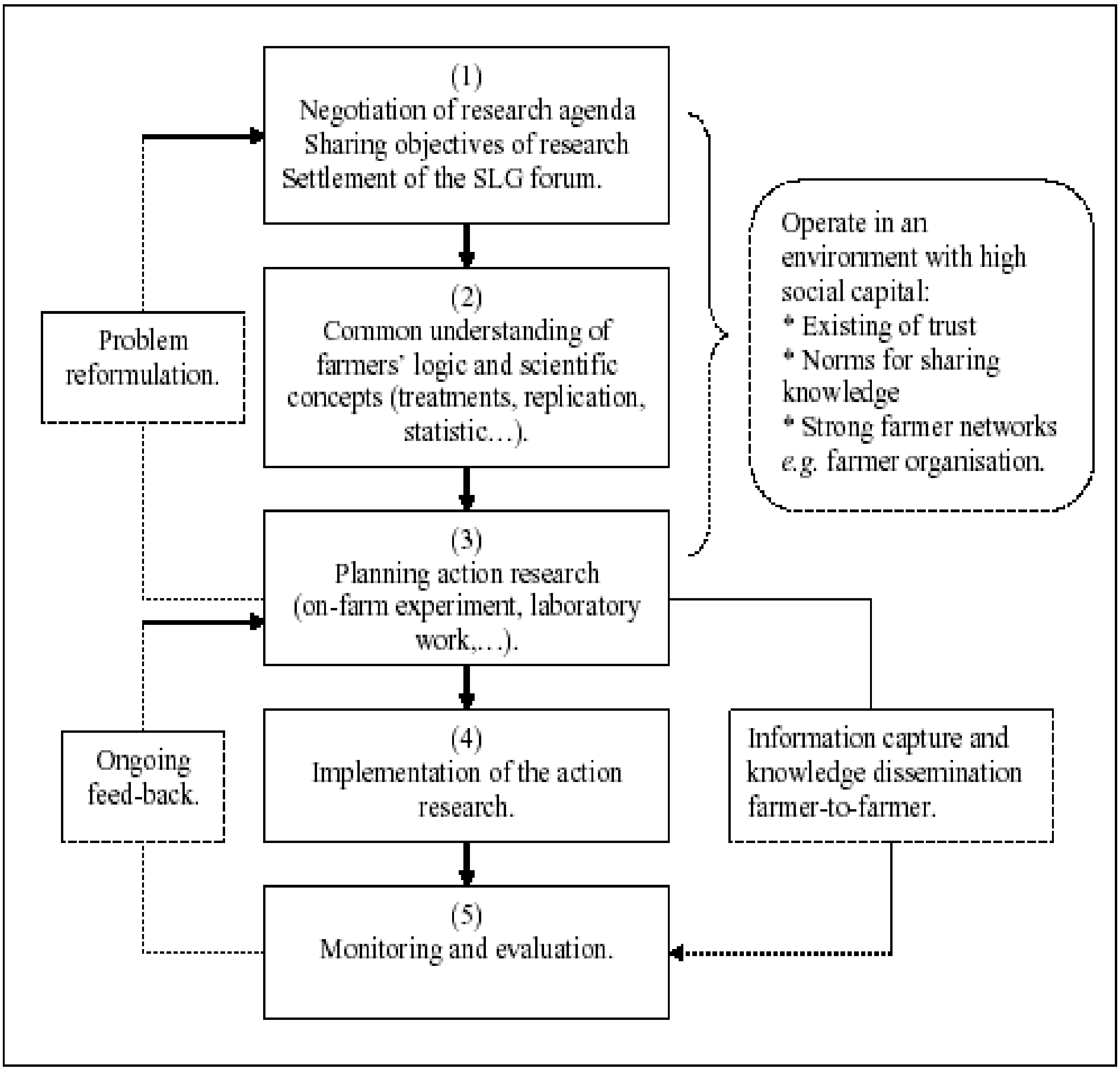


Figure 1: Cooperative experiment framework to facilitate knowledge ownership for more sustainable land management practices to enhance crop production.

of household members. Extensive cassava systems, known in French as '*jachère manioc*', and the planting of egusi melon and cotton in a crop rotation system, are innovative strategies developed by farmers. The peer researcher facilitated a learning environment within which the participants agreed to share their understanding and knowledge about the functioning of these local innovations. Joint understanding of scientific concepts and farmer theories was an important step for the identification of the data to be collected in order to achieve co-research objectives. Farmers' perceptions and claims about biological processes behind the functioning of these local innovations were assessed. In the case of extensive cassava farmer interpretations were

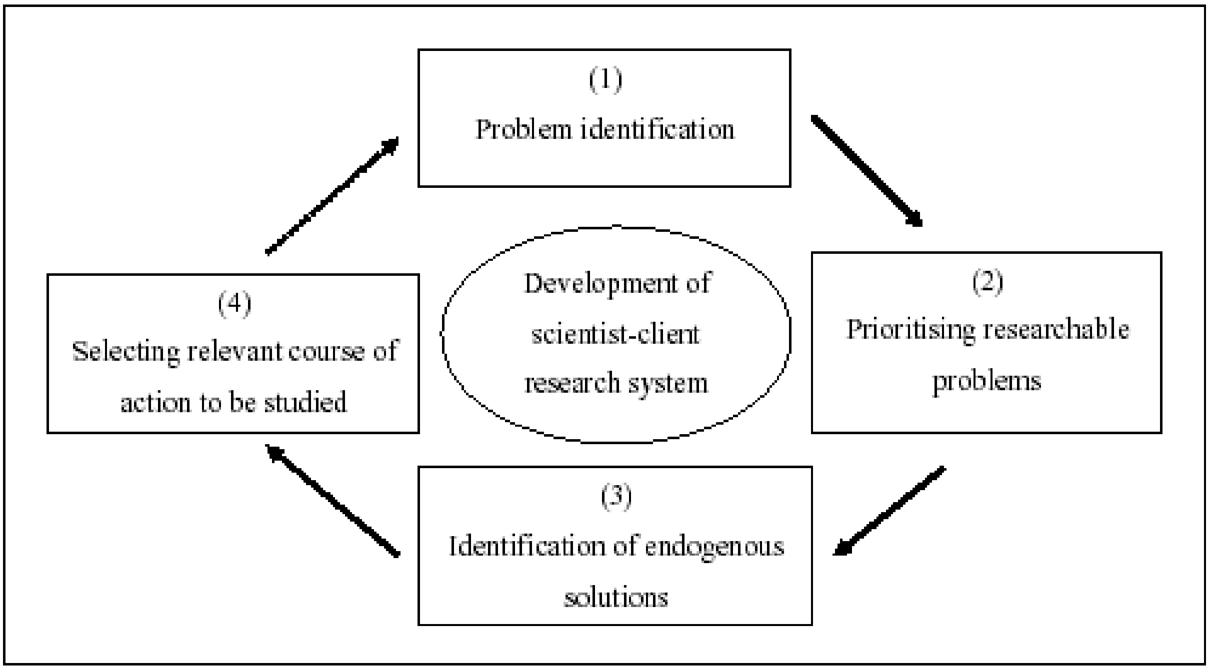


Figure 2: Interactive cycle for research agenda negotiation in the co-research process.

based on nutrient cycling through leaf litter decomposition and earthworm casting activities. Cassava is also mycotrophic, *i.e.* its fine roots are colonised by arbuscular mycorhizal fungi (AMF). With the agreement of the farmers the peer researcher introduced this as an alternative candidate mechanism for the yield improvement of crops succeeding cassava. It seemed an opportunity for the farmers to improve their knowledge on biological activities in the cassava rhizosphere. The contribution of AMF in the improvement of P-uptake by the plant was widely discussed during subsequent meetings.

In the case of cotton rotated with a cereal crop, we exchanged knowledge with farmers on the composition of mineral fertilisers, the role of NPK-SB and urea in plant growth and development, and the residual effect of these fertilisers. Soil-plant relationships were discussed, resulting in dialogue on the relevance of soil and plant analysis to assess soil quality and fertiliser recommendation. The following step consisted of planning joint on-farm experiments aiming to test the effectiveness of farmers' strategies to enhance crop production. We discussed with the SLG what, how and when to evaluate the trial. The secretary (a farmer with secondary school education level) of the group, in charge of recording the minutes for each meeting, planned the different activities to be done in the field. He was assisted by the research assistant and the extension agent. The extension agent played an important role during the diagnostic phase (he introduced the CoS researcher in the village) and was the facilitator during research agenda negotiation with the SLG. Before starting each SLG meeting the secretary presented the minutes of the previous meeting. The secretary of the group was elected by the participants and served also as the group spokesman. Ploughing, sowing, weeding, and harvesting were fully in the charge of the group, while the inputs (seed, fertiliser and pesticide) were provided by the researcher. Data were jointly collected by farmers and members of the research team. The harvested products remained the property of SLG members. In the case of cereal or cassava tubers, part was given to the chief of the village (*balè*) as a customary gift.

Three on-farm experiments and one pot experiment were carried out (Table 1). Both farmer and researcher criteria were used to assess the performance of the different innovations studied. Farmers' criteria mostly concern yield, plant vigour (plant height and leaf colour), soil colour (soil health), canopy formation (ground coverage), litter abundance, and earthworm casting activity. Apart from grain yield, researchers' criteria were determined by standard laboratory protocols for soil fertility assessment and results presented to farmers in a feedback section. The parameters were soil chemical properties (pH, available P, total N, exchangeable K, AMF spores in the soil and root colonisation) and nutrient (N, P and K) content of the plant. All research results were discussed yearly with the members of the SLG. This forum was organised when all laboratory results were available. The scientific results were discussed and compared with farmers' predictions. A farmer field day was organised and the extension service invited in order to end the research process. Farmers presented what they had discovered during the entire co-research process.

Monitoring occurred regularly during the duration of the experiment. Ongoing feed-back was registered in order to reformulate research questions or to adapt the research methodology. Farmers and the research team jointly evaluated the treatments based on the objectives of the experiment. Farmers' attitudes towards, and perceptions of, the performance of the innovation were collected and analysed, to evaluate whether their cropping systems are likely to be affected by the results. Quoting a farmer member of the SLG:, "w*e have learnt a lot from this research process. Before, we did not know that some organisms live in fine roots of cassava. The researcher explained to us that these organises provide food for the plant and contribute in crop yield improvement. The CeCPA (extension service) has never explained this to us. It will be better that the CeCPA agents take example from the CoS research to plan their interventions".*

Characteristics of the SLG

At establishment, group membership was 31 participants including 8 women. Their interest and motivation to be part of the SLG diminished over time, and they started to miss SLG

Table 1: Experiments carried out with farmers during the cooperative experiment regarding the different evaluation criteria and their sources.

Innovations	Experiments	Evaluation criteria	Source of the criteria	Methods used for the assessment
Extensive cassava rotated with maize	Earthworm casting activity and cast enrichment (on-farm experiment)	Cassava canopy formation	Farmers	Ground coverage
		Farmers' perceptions on earthworm	Researcher	Formal survey using open-ended questionnaire
		Number of cast	Farmers	Counting the number of standing cast
		Mass of casts	Researcher	Air and oven drying and weight
		Topsoil (0-10 cm) nutrient concentration	Researcher	pH, organic C, P-Bray 1, total N, exchangeable K, Ca and Mg
		Cast nutrient concentration	Researcher	pH, organic C, P-Bray 1, total N, exchangeable K, Ca and Mg
	Performance of succeeding maize (on-farm experiment)	Crop vigour	Farmers	Plant height, leaf colour
		Yield improvement	Farmers & Researcher	Cob width and length and grain yield
		Soil nutrient concentration	Researcher	pH, P-Bray 1, total N, exchangeable K, N-NH$_4^+$ and N-NO$_3^-$
		Plant nutrient uptake	Researcher	Total N, P and K concentration in the grain[1]
	Contribution of AMF in the succeeding maize nutrient uptake (pot experiment)	Biomass production	Farmers & Researcher	Root and shoot weight
		Plant nutrient uptake	Researcher	N, P and K concentration in the shoot
		Assessment of AMF spores in the soil	Researcher	Wet-sieving technique
		Assessment of AMF colonisation in the root	Researcher	Fine roots are cleared, bleached and proportion of root length colonised by AMF is determined by gridline intersection method
Cotton rotated with maize	Performance of cotton and succeeding maize (on-farm experiment)	Crop vigour	Farmers	Plant height, greenness of the leaves
		Yield improvement	Farmers & Researcher	Cob width and length,grain and stover yield
		Soil nutrient concentration	Researcher	pH, organic C, P-Bray 1, total N, exchangeable K, N-NH$_4^+$ and N-NO$_3^-$
		Plant nutrient uptake	Researcher	Total N, P and K concentration in the grain and stover

[1] As stover is left in the field and recycled this does not contribute to nutrient depletion

meetings. This was due to their heavy involvement in trading. Other members of the SLG then decided to leave them out of the group. Twelve male members showed regular absence at meetings and they also left the group. The final number was reduced to 11 people at the end of the process in 2005. These data suggest that science clubs are only of minority interest when participants do not see an immediate benefit. This SLG was around a nucleus of 5 members of the *Groupement des Producteurs de Coton* (GPC), the farmer organisation involved in cotton production, but was strengthened by volunteer farmers who joined the SLG out of interest. The group can be considered a rural elite: 82% of members had either primary or secondary school level of education, 64% were involved in off-farm activities, especially *Zemidjan* (provision of motorbike taxi services). Only 30% of members were migrants (*i.e.* established in the area in the last ten to fifteen years). It was also a rather tight network from the outset: 64% of the members claimed relationships of kinship or friendship.

Participation was based on voluntarism. Devotion, seriousness and availability were criteria used to strength group cohesion. There was no financial incentive, but the researcher provided a drink after each meeting based on the traditional practices that requires a host to provide food and drink when a rotational labour group is invited to work on a farm. When we asked the members of the SLG why they participated in the SLG 73% of respondents claimed that it was to improve their knowledge. Quoting one member, "*at the beginning, the researcher explained to us that his project was a research project and not a development project. The objective was not to build or construct infrastructure but to improve our cropping systems, especially our soils. We also knew that by giving people a fish they will eat for a day, but by showing them how to fish they will eat for a lifetime. Therefore, by improving our cropping practices we will eat for a lifetime and be less dependent; but the real problem is where to sell and how to have better prices for our farm produce*". This last statement clearly implies that farmers have an interest in science-based solutions, but have other major problems, in this case access to markets and better prices.

Initially, farmers did not expect any physical or financial incentive. After discussing topics related to the experiment, farmers often came up with specific issues of their own (such as market access and better prices for farm produce). During the survey, 9% of the respondents acknowledged that they worked with the SLG out of curiosity, but that they also hoped that the researcher would bring a project to develop their village. But 18% of the respondents stated that they participated in the SLG because they expected that lessons from the group discussion would be important and help them to improve their productivity and income. Organising exchange visits, fostering friendship, and encouraging members of the group to assist each other when they had specific problems not related to co-research activities, were strategies developed by the researcher to strengthen group cohesion.

Relative impact pathways

From the surveys with individual farmers, 56% of respondent responses can be classified under the heading of improvement of social capital while 44% belong to the improvement of human capital. In other words, knowledge enhancement using the CoS approach tends to be viewed more in terms of its impact on the group than on individuals. One of the aims of CoS is to stimulate this process of embedding science within the collective consciousness of African rural communities.

The scoring results before and after evaluation of the co-research process are presented in the kite diagrams. With regard to human capital (Fig. 3A), farmers acknowledged that from the results of soil analysis they know better the fertility status of the three main local soil types (*ilè kpukpa*, *ilè ignin* and *ilè dudu – red, white and black earth*). According to the scaling index applied to the situation before and after co-research farmer knowledge moved in a positive direction (it improved by 2 points). Farmers' knowledge about the role of NPK and urea, and the contribution of arbuscular mycorhizal fungi (AMF) in nutrient uptake was more improved (3 points each). Farmers' knowledge on nutrient cycling, earthworm and cast enrichment, and signs of nutrient shortage based on leaf discoloration enjoyed a slightly lower assessment (improvement of 2 points). Farmers claimed the least knowledge gain for the topic of residual effect of mineral fertiliser in cotton-maize rotation system (something perhaps already widely understood).

With regards to social capital (Fig. 3B), farmers appreciated positively (3 points increase) the establishment of the SLG forum. Farmers acknowledged that with the establishment of the SLG, they shared knowledge better than before, and that social cohesion of the group had been improved (2 points each). In particular, they acknowledged that before the co-research activities, no scientist had visited their village. They valued especially highly (4 points) increased scientific interest in Ouoghi, now known world-wide through scientific reports produced by the researcher. Finally, members of the SLG recognised that they have improved their cropping practices based on knowledge gained from the SLG forum and via the capacity of the group to communicate and manage on-farm experiments (2 and 3 points respectively).

Discussion and conclusion

Relevance of the co-research approach

The main point of doing co-research with farmers is first of all to facilitate joint discovery by scientists and local farmers, and second, to develop capacity to identify and exploit opportunities for applying such discoveries to locally specific situations. The research approach enriched the widely used model of on-farm trials. At the beginning of the process, emphasis was put on negotiation of the research agenda with stakeholders. Villagers participated in joint problem analysis, leading to action plans and the formation of a local institution, *i.e.* the SLG forum (platform). To achieve this, all stakeholders interested in agro-technical development agree to learn from each other, and institutional support should encourage this co-learning process. Co-research presents two aspects: inter-disciplinary interactions between the researchers (local and international scientists from natural and social sciences), and interactions between farmers, extension agent and researchers.

In general, in Benin, the R&D program is more involved in adaptive on-farm experimentation (Nouatin, 2003). Under the farm trial model farmers are passive recipients of research results won by professional scientists because, apparently, there is little or no emphasis on the process of research agenda negotiation and subsequent mobilisation of farmers to contribute to the experiment and assessment of results. A result is that similar recipes tend to recommended for all farmers. Aware of the weak adoption of improved technologies, due to the ineffectiveness of the 'participatory' research approach implemented, the R&D Centre Savè is now experimenting with the teachers-grassroots-farmers approach (Amadji *et al.*, 2004). The approach is based on the assumption that, by facilitating learning at each school level concerning improved land management technologies, the grassroots learners will teach their parents at home. This approach has newly started and the R&D team is expecting to have more impact compared with the formal approach so far used (based on the adage "see and believe").

The co-research approach differs markedly from either of these two R&D approaches. While R&D uses a multidisciplinary approach, solutions of the problem are devised by scientists alone, who then ask farmers to test or adopt a technology of which they had no earlier knowledge. The R&D approach does not draw on indigenous technical knowledge for problem diagnosis, or appraise opportunities to test the effectiveness of these technologies. The co-research approach, by contrast, invites farmers to become 'co-researchers', and scientists to become 'co-learners'. Farmers are involved in decision-making even during the setting up of the research methodology. The co-research approach incorporates learning by building on farmer experience, and its wider usage would considerably enrich the formal model of participation in use in Benin agricultural system.

The co-research approach draws on a legacy of participatory thinking – *e.g.* Participatory Learning and Action Research (PLAR) (Defoer and Budelman, 2000), Farmer Field School (FFS) (Kenmore, 1996; Pontius *et al.*, 2002), and Local Agricultural Research Committees (LARC) (Braun *et al.*, 2000) -. These platforms call for a much closer engagement of agricultural research and extension with rural society, and in building local institutional structures and processes for agricultural development. They aim to make R&D more relevant by placing farmers themselves at the centre of the development processes. What is new with the

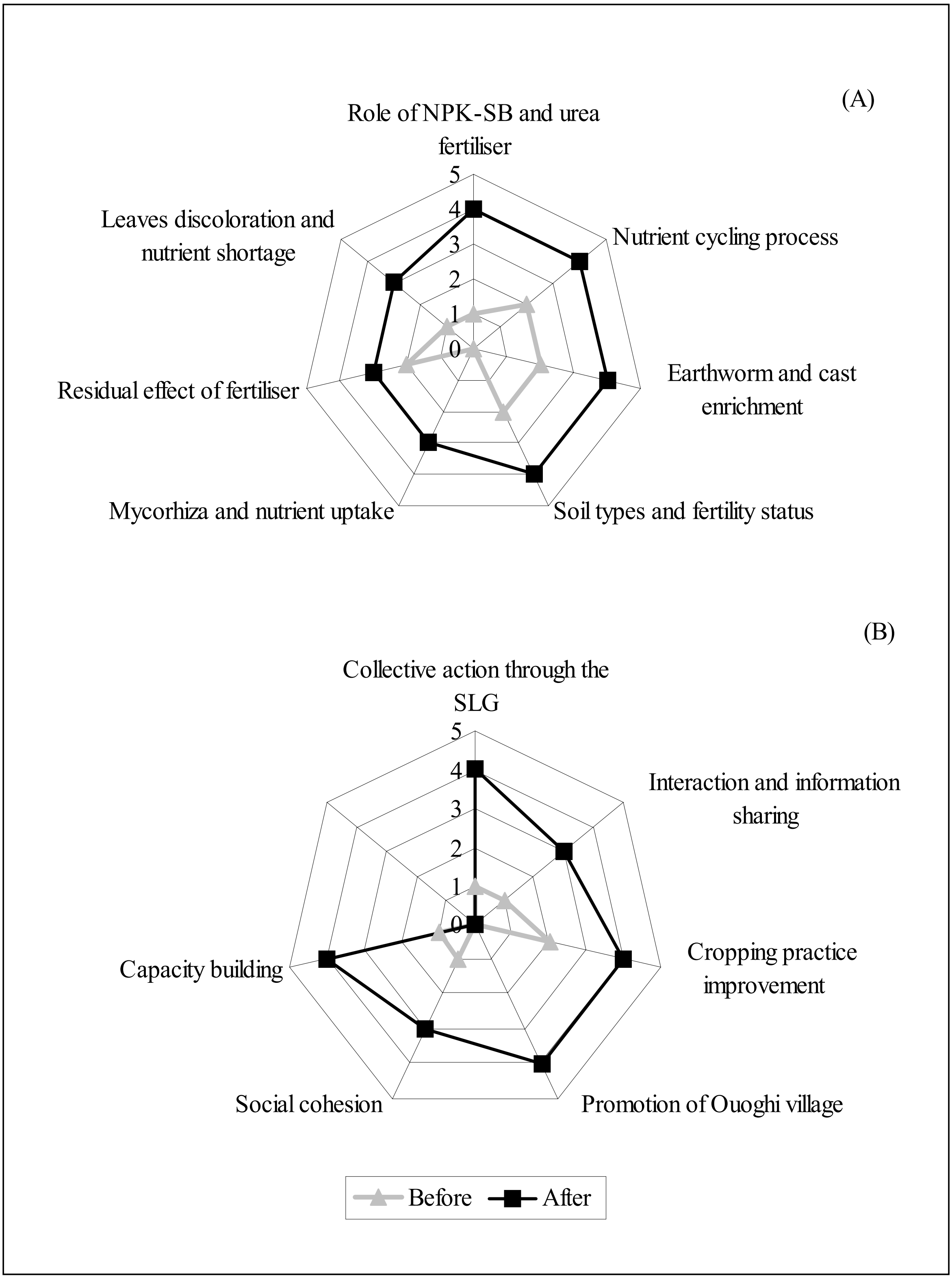


Figure 3: Kite diagram presenting the score of each indicator of (A) human and (B) social capital as identified by farmers before and after the co-research process.

CoS co-research approach is that it emphasises joint discovery of new knowledge by farmers and researchers via a conscious attempt to democratise science through decision making by informed consent of a research-oriented group. This approach recognises that farmers are key stakeholders in the outcomes of scientific investigations, and that their active participation in generating these outcomes, be it by identifying the problems that require research, by specifying the context, or by helping to determine what works, is likely to change the collective representations through which soil fertility ideas are discussed at the local level. Another key difference, is that CoS payed attention to the pre-analytical choices and made them explicit (Giampietro, 2003; Nederlof *et al*., 2004; Röling *et al*., 2004). This allowed quick identification and utilisation of the small windows of opportunity.

Is co-research with farmers a route towards sustainable agricultural innovation?

A major argument for negotiating activities with beneficiaries and involving them in the implementation phase as a route for durable agriculture development is that local experts know better about their complex situation. Hounkonnou (2001) noticed that a rare point of 'light' in African development is 'local dynamics', the way local people themselves seek to generate better lives. He also argued that effective interventions must be anchored in such local dynamics. Clearly, farmers and communities need to be empowered to solve their own problems, and access technologies through methods that emphasise active participation (Hellin and Higmann, 2001). The main results of the co-research here reported make a case for considering farmers as potential researchers in partnership with professional scientists. Strengthening of social and human capital took place in the course of the co-research . This provides evidence that farmers consider strengthening of organisational capacity as an important aspect of attempts to better manage natural resources and community assets.

The importance of reinforcement and continued deployment of social and human capital in a society for successful interventions and community development was highlighted by Grootaert (2001) and Sanginga *et al*. (2004). Pretty (2003), documenting the relevance of social capital for community development, argued that social capital lowers transaction costs of working together and facilitates cooperation, relations of trust, reciprocity and exchange, common rules, norms and sanctions, and connectedness in networks and groups. The account above suggests that members of the SLG strengthened their social relationships (involvement of migrants, for example) and considerable mutual trust was established between the group and the research team. This helped create a favourable environment for innovation. The farmer evaluation also suggested that co-research improved the group's ability to engage with other external agencies (extension service, credit agencies, project workers). Working with scientists gave villagers some confidence that they could handle other visitors to the village. Farmers acknowledged that they improved their cropping system. As a further example, mineral fertiliser application is now done in a hole made close to the plant (with the hole closed after applying the fertiliser) where previously, due to time constraint after application, the hole was not closed. Closing the hole reduces nitrogen volatilisation and losses due to runoff.

It can be argued that more important than the results of the on-farm experiment, it is the approach and the process showing how farmers and scientists can interact for sustainable soil fertility management that needs to be disseminated. This means that even though the results of co-research may vary from case to case, the process itself applied across a wide range of situations would cumulatively empower farmers for effective action concerning sustainable agriculture development. But to achieve this, the presence of active extension or development workers with sufficient motivation and skills (or willingness to learn and taking farmers seriously) to be community development facilitators will be needed. One strategy might be to build on small, pre-existing and well-led farmer groups (10-15 members) able to draw on substantial amounts of long-term social capital (group cohesion and effectiveness), rather than investing heavily in forming new groups.

The main challenge is whether the actual institutional environment is favourable for scaling-up this new form of collaborative research with farmers. In fact, scaling-up successful research initiatives will require that ownership be built among key stakeholders (university and national research institute, national extension service, NGOs, private sector, government, etc.). This includes the need to develop a shared vision and build confidence and capacity among less powerful farmers (Snapp and Heong, 2003). The negotiating process to establish mechanisms of linkage between community and district level institutions is vital for scaling-up of the co-research process. However, scaling up a participatory research processes also requires new skills, such as the management of meetings in a participatory and democratic way, the ability to learn from farmers and explain technical issues in local languages, and open-mindedness about different worldviews and explanations. A start could be made by seeking to improve communication and motivation among stakeholders (*e.g.* by setting up a national participatory research organisation, nominating a national farmer research day, offering prizes for innovative co-research). Directors of national research organisations could set a lead by declaring an orientation towards action research focused on farmers' needs and objectives. Even so, it is clear that scaling up the collaborative research process will require considerable investment in human resources, in new educational facilities, and in building quality partnerships for joint learning and action research.

One key problem is that research systems in developing countries currently suffer from declining numbers of extension personnel (Nouatin, 2003). This is a factor in limiting farmers' access to new technology. Funding and structural reforms are urgently needed. A step forward will be to reorganise such activities in relation to market conditions, farmer networks and agro-ecological zones. A focus on key commodities, in the context of the participatory approach here advocated, might motivate farmers towards greater involvement in co-research, and help build a platform of expectation and demand, without which research will continue to seem irrelevant to many farmers.

Lessons learned from the farmer self-evaluation of co-research reported above suggest that it is important to develop a critical mass of researchers - especially field researchers who are capable of co-learning with farmers, to quickly build useful amounts of human and social capital for co-research purposes, and to create institutional commitments and clarity in understanding of roles, responsibilities and expectations among the different partners. The InterAcademy Council report (IAC, 2004) on the future of African agro-technology has recently suggested that African agriculture needs knowledge and development institutions reflecting farmer needs. This should be the main approach to identify new avenues of research. The co-research approach fits well within this perspective. IAC objectives might indeed be best accomplished by involving farmers in the research process itself, rather than being limited to trying out and evaluating innovations ‘off the shelf”. In appreciation of the complexity of African farming systems and the hybrid nature of many communities, it will be important to apply a co-research policy only in ways that reflect rural diversity. This study has shown that some farmers are keen to become involved in creating new knowledge, and that they are often quick to form relevant group structures, even if they hope to access a range of developmental benefits, and not scientific knowledge alone. There is scope to build a new popular, democratic approach the agro-science among rural communities in Benin.

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Chapter 7

Land tenure and sustainable soil fertility management in the Centre Benin: towards the establishment of a cooperation space among stakeholders

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Chapter 7

Land tenure and sustainable soil fertility management in the Centre Benin: towards the establishment of a cooperation space among stakeholders

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Abstract

Tenure arrangements were studied in central Benin, with special attention to factors diminishing or enhancing mutual trust between landowners and migrant farmers. Two contrasting tenure arrangement systems occur. The first is found in Ouoghi village, where landowners and villagers are organised around the *Association de Développement Economique et Social du Village de Ouoghi* (ADESVO). The second is found in the Boubouhou area, where land tenure is managed by landowner lineages. In both systems migrants are not allowed to grow trees, for fear that this will strengthen migrants' ownership rights. Originally, migrant farmers were incorporated through a land-for-labour transaction. Nowadays, this practice has irretrievably changed due to the increasing importance of monetary transactions in agriculture and the presence of economic opportunities outside agriculture, which constrain labour availability. The problem to be overcome is how to change mutual perceptions of tree planting as a covert claim to land ownership, since agroforestry is a potential key to soil fertility maintenance. We facilitated alternative formal written-down land use rules, including adoption of agroforestry and improved soil management practices. Negotiation proved to be more complicated with landowners in Boubouhou because they did not want the existing bilateral relationships with migrants to be changed. But in Ouoghi migrants and owners had already created an institution for collective management of land, which allowed for better interaction and communication among the stakeholders. Here, it was easier to integrate technology components into formal tenurial arrangements. An attempt was made to build soil quality monitoring by scientists into the negotiation process.

Keywords: soil quality, livelihood improvement, stakeholder negotiations, power relationships.

Introduction

In Benin migration is an important aspect of livelihood-oriented agricultural systems. In migration-based systems, cropping strategies are adapted to take account of labour availability, soil fertility, the need to grow various crops, etc. Migration serves as a social strategy to release pressure on the land in one area, while simultaneously increasing pressure on land and social relationships elsewhere (Igué, 1983; Saïdou *et al.*, 2004; Sambieni, 2004). In most zones of immigration, arrival of migrants has a direct impact on tenure. Originally, immigration involved a system for incorporation of migrants as clients of landowners. Clients supplied agricultural labour to their landlords, and were given small pieces of land to cover their own subsistence. More recently, this system of labour-for-land has tended to disappear due to the increasing importance of money-for-land transactions in the economy. New rules have emerged, namely establishment of yearly rent in place of labour-for-land. These new systems may not always be favourable to newcomers.

Tenure security and agricultural productivity are interconnected. Greater tenure security increases farmers' confidence that they will benefit from land improvements over the longer term (Maxwell and Wiebe, 1999). These authors also hypothesised that tenure security increases the supply of formal credit through the creation of tradable collateral. Both effects could result in greater short-term investment in inputs and greater long-term investment in land-conserving technologies, leading to a higher, sustainable production. But the relationship could also run in the other direction: land improvement and permanent cropping may gradually increase tenure security. Fallowing could reduce tenure security, especially when a Lockean view is dominant that the land belongs to those who work on it.

The tenurial arrangement in the transitional zone of Benin was first considered from the standpoint of a prisoner's dilemma (Saïdou *et al.*, 2004). The importance of prisoner's dilemma in land management was highlighted by Hardin (1968). Prisoner's dilemma assumes that on communal lands there are no rules regulating access whatsoever, and hence only private property can avoid the tragedy of the commons. However, customary tenure systems and rules on the use of communal land usually do restrict access. Communal land does not imply free access. Increases in populations can therefore still lead to improvement of the fertility of the land by the adoption of new technologies, so long as security in tenurial arrangements is provided (Fairhead and Leach, 1995; Mathieu, 1996; Tiffen *et al.*, 1994). The best way out of the prisoner's dilemma is through the build-up of mutual trust (Hardin, 1968).

The issue is how the existing – deficient - tenancy system can be modified to give a win-win incentive structure to motivate migrants as well as landowners to better land management. This makes it crucial to understand which factors enhance or diminish mutual trust in this specific context of soil fertility maintenance. The basic idea of the present work is that trust in institutions depends on different stakeholders seeing advantages in co-operation and that improved technology could be a basis for increasing co-operation. Both parties, landowners and migrants, are heterogeneous and have a variety of potentially conflicting interests (Adjei-Nsiah, 2006; Dangbégnon, 1998; Edja, 1996; Saïdou *et al*., 2004; Sambieni, 2004; Tchégnon and Biaou, 1995). Socio-economic dynamics are also relevant: changes from subsistence to cash-crop agriculture, expanding regional markets due to better transportation facilities, and increased pressure on labour availability due to greater opportunities outside agriculture. The increasing importance of monetary transactions in agriculture could undermine trust in the institution of land tenancy because landowners are tempted to exploit migrants through levying high rents before harvests, and migrants can respond by mining the land.

A diagnostic study in the transitional zone of Benin (Saïdou *et al*., 2004) has shown how soil fertility issues are embedded in tenure arrangements and how these in turn, are embedded in a world of power and trust. The present paper aims to answer the following question raised during the diagnostic study: how can new forms of trust be built that motivate landowners and migrants to work jointly for fair solutions to problems of soil degradation? The answer to this question could contribute to sustainable soil fertility management. A potential solution would be to construct win-win scenarios around new technologies, using adoption of best practices as an incentive for offering better tenancy terms, with a role for scientists in helping open up pathways to sustainable management and monitoring of results, *i.e.* acting as honest brokers to both stakeholder groups. Such an attempt is reported in this study.

Access to land and tenure arrangements

Over time, the vital role that land plays in sustaining life for human beings has led societies to establish arrangements concerning ownership and use of land, usually referred to as land tenure (Cotula *et al*., 2004; Fraser, 2004; IIED, 1999; Manyong and Houndékon, 2000; Maxwell and Wiebe, 1999). Land tenure involves rules and procedures governing rights, duties, liberties and exposure of individuals and groups in the use of and control over basic resources (De Zeeuw, 1997; Matlon, 1994; Platteau, 1996). These rights are recognised in customary ('traditional') and statutory (formal) law, as well as through institutions of marriage, power, and inheritance. Customary land tenure is characterised by its largely unwritten nature, being based on local practices and norms, and being flexible, negotiable and location-specific. It is often grounded in rights held to have been established through first clearance of land or conquest (Berry, 1993; Cotula *et al*., 2004; Woodhouse, 2003).

Subsequent investment becomes a key factor in strengthening claims over land

(Manyong and Houndékon, 2000). At its simplest, investment in clearing land by cutting and burning vegetation forms the basis of customary authority usually held by (or transferred from) the descendents of the first settlers who cleared the land. People unable to establish visible investments or to maintain continuous production (*i.e.* continuous occupation) are mostly more vulnerable being usurped (Woodhouse, 2003).

The centrality of land in all dimensions of rural African life means that the analysis of land tenure issues should be broadened to include issues such as land use, agricultural production efficiency, conflict management mechanisms, power relationships and social position (Lavigne Delville, 2004). The most common land tenure system found in sub-Sahara Africa is lineage-based ownership of land where individuals belonging to a particular lineage (extended family based on descent from a common ancestor) have access and use rights to land that is held in trust by the community. In such a system juniors work for elders, and juniors (ideally) become elders in turn. Rights to different types of land are typically accorded to individuals through membership in the kinship group, which helps to ensure that juniors will continue to work for elders and inherit their position in time.

Other modes through which individuals have access to land include inheritance, purchase, gifts, sharecropping or renting (Lawry *et al*., 1994). Sharecropping is comparable to renting, except that payment is made in kind based on fractions of the crop being claimed by land user and landowner. It is widely found where owners lack resources for investment in land and where farming tasks are low in skill content.

In the central zone of Benin, landholding by native farmers is based on usufruct (Le Meur, 2002). Native farmers acquire their initial plots through intrafamilial inheritance and/or transfers of rights from village headmen. Inheritance passes exclusively from parents to male children equally (all brothers have equal rights, whether older or younger). The customary inheritance rule is simple with regards to women; they are unable to inherit land. However, women farmers commonly cultivate land they receive from their husbands. In the case of divorce, the land returns to the husband's family. If the husband dies, the widow can claim usufruct rights on the land on behalf of her small sons until they take over at their majority.

Because there are no guarantees that farmers who rent land will reap the benefits of long-term soil conservation, tenant farmers mostly use management strategies that maximise short-term production even if this compromises future soil fertility (Fraser, 2004). Land tenure security is thus a prerequisite for investment in land (Lavigne Delville, 2004; Mathieu, 1996). Potential soil management innovations based on tree planting can create long-term interests, and thus a quasi-ownership. The question is how to develop tree planting in such a way that it offers positive inducements for both landowners and migrants.

The diagnostic study showed that soil fertility is a problem in the study area (consistent with the assumption that the land is being exploited in the short term by large numbers of migrant farmers), but that solutions are not simple, because fertility issues impinge on institutional as well as technical domains. The social and institutional dimensions of particular technological solutions clash with those of other technologies. This is why the literature shows an interest in strengthening locally-based institutions for dispute resolution and land management (Firmin-Sellers and Sellers, 1999; Fred-Mensah, 1999; IIED, 1999). However, there is little work on how such local land-technology institutions might best function. This is the topic the present paper seeks to address.

Methodology

Study area

The transitional zone of Benin is characterised by a Guinea-Sudan climate with unimodal rainfall distribution. It is located between 7°42'and 8°45'N and 2°15'and 2°45'E. The rainy season lasts from April to October. The annual rainfall (1974-2004) is about 1100 mm (Savè weather station). The area is essentially dominated by tropical ferruginous soils (Dubroeucq, 1977) originally from Precambrian crystalline rocks (granite and gneiss). The soils are deep without laterite and often have a reasonable inherent fertility. The total population is about 68,000 inhabitants, of which 37% are migrants. Population density averages 30 inhabitants km^{-2} (INSAE, 2004). The indigenous population are the *Tchabè* (a group speaking a dialect of the Yoruba language) and *Peulh* (Fulani) herders, scattered over the entire region.

Origin of migration flux

Migrants started to establish themselves in the area before 1960 due to the introduction by the French colonial regime of labour-intensive cash crops, such as tobacco, cotton, and groundnut. This migration process was stimulated by the presence of regional markets including Glazoué, Parakou and Malanville where the demand for agricultural products (yam, maize, cassava, cowpea, sorghum etc.) was high. Consequently, farmers had a high demand for seasonal labourers, many of whom came from the hilly and over-populated Atacora-Donga area. Thereafter, natives facilitated land access for the migrants in order to stimulate them to settle, so ensuring labour was permanently available. The number of agricultural labourers in the area increased, which fostered a vast migration network, leading to the emergence of new villages close to the localities in which migrants had been offered land to farm. Table 1 presents information on the migrant communities found in the different villages studied. Nowadays, the area is mainly populated by the *Otamari* from Natitingou and Boukoumbé (Atacora), the *Yom* and *Lokpa* from Djougou and Copargo (Donga).

Table 1. Migrant ethnic groups and their periods of establishment in the different villages.

Villages	Period of establishment	Ethnic groups	Origin of each groups in the Atacora-Donga department
Boubouhou	1968	Yom, Otamari, Wama, Natimba, Lokpa, Gourmantché, Sola.	Djougou, Natitingou, Toucountouna, Boukoumbé, Ouaké, Tanguiéta.
Igbo Iyoko	1987	Wama, Natimba, Otamari,	Natitingou, Toucountouna, Boukoumbé, Tanguiéta.
Elakpoo	1975	Yom, Otamari, Lokpa, N'yendé	Djougou, Natitingou, Ouaké, Cobly.
Kogbogoun	1962	Otamari	Boukoumbé, Natitingou.
Ouoghi gare/Kpatcha	1950	Yom, Otamari, Wama, Sola, Lokpa, Bariba.	Copargo, Natitingou, Ouaké, Kouandé.
Ouoghi central	-	Tchabè	Native

The willingness of farmers in more isolated districts to seek work as farm labourers was stimulated in Benin during the colonial period by French demands for taxes paid in cash. Men of the age to pay taxes turned to labour migration as often their only realistic option to obtain money. Taxation stimulated migration towards Borgou (N'dali and Tchaourou) and the central zone of Benin (Glazoué, Bantè and Savè) (Fig. 1). There were also migratory movements to Nigeria, Ghana, and Côte d'Ivoire. In some areas land degradation, leading to a decrease in soil fertility and reduction of crop yields, added to the pressure to migrate. The source area is mountainous and now faces land scarcity since only 45% of the area is favourable for agriculture.

Research methods

The study was carried out from January 2003 to June 2005, as a follow-up of a diagnostic study carried out from June to November 2002 (Saïdou *et al*., 2004). The methodological approach used for the negotiation process for sustainable tenurial arrangements was inspired by Ravnborg and del Pilar Guerrero (1999). The general objective is to develop strategies to remedial problems of soil degradation through consensus building among the stakeholders involved in land tenure arrangement. The work described can be considered action research involving five steps, based on in-depth survey of farming systems among native and migrant farmers and on assessment of their conflicting interests. The action research began with stakeholder identification, followed by the introduction of the idea of mutual interdependence among these stakeholders. This

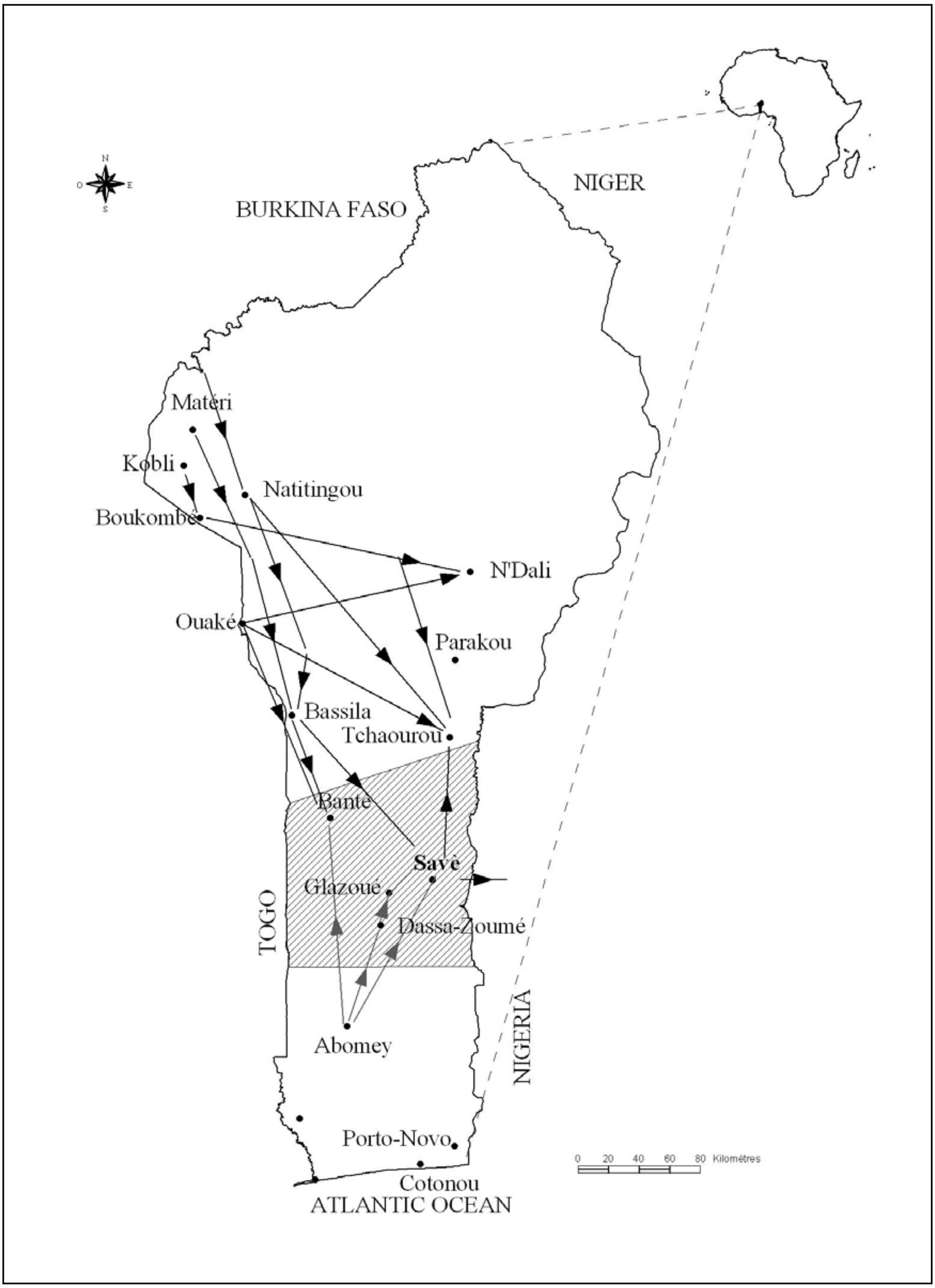


Figure 1. Map of the Republic of Benin with the transitional zone (hatched) and the migration flow (dark arrows indicate migration flow from Atacora-Donga and grey arrows indicate migration flow from Abomey plateau).

provided the possibility to arrive at a joint perception of causes and consequences of land degradation, and of the conflicts that ensued. The next step involved the possibility for parties to propose alternative arrangements. These were discussed and at the end a consensual alternative arrangement was agreed.

The formal survey was carried out from May to August 2004 using an open-ended questionnaire. The key informants to be interviewed were identified during the community-based platform meetings. In total 70 migrants were interviewed. Several individuals (especially community leaders) were visited many times to follow up on a given topic. A snowball sampling technique was used to identify stakeholders and key informants.

Statistical analysis

During the diagnostic study, we noticed that the regularity of rent payment is the main source of conflict between migrants and landowners. A probit model was used to analyse the explanatory variables determining migrants' ability to pay yearly rent (Griffiths *et al*., 1993; Liao, 1994). We considered as dependent variable the ability of migrants to pay the yearly rent. We hypothesized that rent payment is linked to the total surface cultivated, total surface cultivated for cash crops, surface cultivated for cotton, household size, use of labourers, number of people working for the household farm, migrant age, duration of stay in the area and migrant itinerary before establishment in the area.

Results

We will discuss 1.) migrant and native farmers' cropping systems and their impact on soil fertility; 2.) evolution of tenurial arrangement and which ones might be relevant if new or alternative local institutions are to emerge; 3.) strategies developed by migrants to obtain farmland and labour; 4.) power relations that might influence or determine the types and forms of alternative tenurial arrangements; and 5.) factors enhancing or diminishing mutual trust between migrant groups and landowners. Finally 6.) the negotiation process for establishing cooperation for sustainable tenure arrangement will be described.

The study compares two different tenurial arrangement systems. The first occurs in Ouoghi village and surrounding migrants' villages where landowners and villagers are organised around a village development association (ADESVO). Rents are collected by groups mandated by ADESVO and are used mainly for collective purposes (e.g. better medical services, support for schools, and a water supply that benefits both natives and migrants). The second system occurs in Boubouhou and neighbouring villages (Elakpo, Igbo Iyoko, and Kogbogoun) where the migrants pay rents to landowner collectivities (extended families) in Savè, especially the

Amushu group (major land owners in this area). Rents are not used for collective purposes but are controlled and disbursed by the leaders of the collectivity (family elders).

Livelihood improvement is the main goal of migrants. Agriculture is the only choice they have to achieve this goal. The tenurial system has a large impact on the opportunities for these migrants. For a better understanding of the dynamics of the tenurial arrangement it is necessary to look at the land use system of the different groups. Understanding these systems is a pre-requisite for any discussion of alternative tenurial arrangements.

Cropping systems of the different groups and their impact on soil fertility management

The cropping system of the migrants is quite highly market oriented. The main cash crops cultivated are cotton, yam (partly used as food crop), egusi melon, groundnut, soybean, maize (partly used as food crop), and rice. Sorghum, cowpea, and cassava are food crops. The indigenous people cultivate annual crops mainly for subsistence, their main crops being cassava, maize, yam, cowpea, and egusi melon. The cash crops are cashew, hot pepper, and groundnut. Migrants cultivate on average 3.4 ha for cash crops and 1.6 ha for food crops, whereas the indigenous farmers cultivate 1.0 ha for cash crop and 1.4 ha for food crops. But this excludes cashew. On average natives have 4.4 ha of cashew. Migrants are not allowed to plant trees (including cashew). The greater area of cash crops (excluding cashew) grown by migrants is partly explained by the fact that migrants have the opportunity to mobilise seasonal migrant labourers. In part, however, it is explained by the fact that indigenes are more interested in cashew (a crop forbidden to migrants). Mostly, the seasonal migrant labourers return to their home village after earning sufficient money. However, some stay in the area, seek to make their own farm and join the group of migrant newcomers. As animal traction is not practised in the area, migrants who settle permanently cultivate sizeable areas (more than 4 ha) only by accommodating groups of seasonal labourers originating in their own region. Seasonal labourers are mainly involved in ploughing and weeding. Most of the seasonal labourers prefer to work for someone from their area, whom they trust, than work for native farmers who only pay wages after selling the harvest.

Native farmers practise agriculture more intensively (the land is cropped for a long duration, as cashew is a tree crop). Accordingly, they do not clear new lands every year for yam cultivation, as the migrants do. Native farmers actually grow fewer yams than migrants. Yam landraces cultivated are usually integrated later in the cropping cycle, but the natives also have some varieties needing virgin land. After three years, the field where they have planted food or cash crops is planted with cashew. While the cashew trees are still small food crops are cultivated under the trees. Long-term fallow is not common on cultivated land where farmers grow cashew.

Migrants practise a more extensive agriculture because they engage seasonal labourers or migrant newcomers still willing to sell part of their labour. The land is cropped for a shorter duration (mostly 3 years) before it is left to fallow for a short interval (2-3 years). Because the land is left to fallow for a short duration, farmers do not lose claim on land they use but do not own. Extensive cassava (*jachère manioc, cf.* Saïdou *et al*., 2004) is also a strategy for migrants to preserve their claim on the land. However, a long-duration fallow (at least 10 years) may be considered by landowners as abandonment, which makes the land available for allocation to migrant newcomers. The widespread local view that the land belongs (for the period of use) to

Table 2. Evolution of the tenurial arrangement in the Ouoghi and Boubouhou area.

Periods	Tenurial arrangement		Remarks
	Boubouhou	Ouoghi	
From 1960 to 1985	- Land use right (i*tchakolè*) consisting of Sodabi[1] offered to the landowners - Symbolic quantity of food crops offered to the head of the collectivity at the end of each cropping period - Labour-for-land	- Land use right (i*tchakolè*) consisting of Sodabi offered to the *Balè* - Symbolic quantity of food crops offered to the head of the *Balè* at the end of each cropping period - Labour-for-land	The i*tchakolè* is paid once when the migrant established
1986 to 1990	- *Itchakolè* of F CFA 5,000-7,000 (€ 8-11) - Labour-for-land	- *Itchakolè*: alcohol drinks, kola nuts and F CFA 2,000 (€ 3) - Labour-for-land	Migrant is not allowed to plant trees
1991 to 1998	- *Itchakolè* of F CFA 5,000 to 10,000 (€ 8 to15) - Rent fixed at F CFA 10,000 (€ 15)/ha/year	- Documented land use rules between the migrant and the ADESVO - *Itchakolè* fixed at F CFA 5,000 (€ 8) - Rent of F CFA 2,000 to 5,000 (€ 3 to 8)/ha/year	- In Ouoghi area, the rent has increased from F CFA 2,000 (€ 3 in 1991) to 5,000 (€ 8 from 1994 to 1998)
From 1999 onwards	- *Itchakolè* fixed at F CFA 5,000 to 10,000 (€ 8 to15) - Rent fixed at F CFA 15,000 (€ 23)/3 ha/year	- Documented land use rules - *Itchakolè* fixed at F CFA 5,000 (€ 8) - Rent fixed at F CFA 5,000 (€ 8)/ha/year	In Ouoghi the amount of rent is flexible

[1] Local distilled drink containing alcohol made from palm wine.

the person who works it is an important factor in tenure security.

Evolution of the tenure institutional arrangement

The success of alternative tenurial arrangements may well depend on the types of previous institutional arrangement. It is important to learn from former experiences when one wants to establish new institutional rules for land use. Therefore, we studied the evolution of the existing tenurial arrangements. Table 2 summarises land use rules in both areas from 1960 onwards. Before 1985 the tenurial systems in Ouoghi and Boubouhou area were similar. In the case of Ouoghi village, migrants (named locally *Agatu* or *Kpasi,* which literally means labourer in Yoruba) who wanted to establish themselves in the area were introduced to the *Balè* (contraction of *baba ilè,* lit. "father of the land" in Yoruba, in effect "village head") who represented landowners and the *Kabiyesi* (oba or king of Savè) by the indigenous sponsor (*tuteur* in French, *i.e.* landlord) who accommodated him. In the case of Boubouhou area, migrants were introduced to the collectivity of landowners (*collectivité des propriétaires terriens* in French; o*mo onilè, children of the land,* in the local language). In both cases, gifts were offered to the landowners and/or the *Balè* to implore the blessing of the ancestors and the divinity so that the land would prosper. At that time, the migrant was considered as the guest of village (*alédjo wa)*. In fact, being a guest implied an obligation to provide labour in return for being allowed to settle in the area. The payment (partly tribute, and only partly rent) suggests labour was the more important factor in the beginning.

From 1985 to 1990, tenurial arrangements changed. The migrant offered gifts to obtain a land use right (i*tchakolè* in the local language – similar to *isakole* among Yoruba farmers in Nigeria as described by Berry [1993]). The amount of money paid for i*tchakolè* depended on the fertility of the farmland. The tribute included the obligation to work for the landowner; this being similar to the situation where a new migrant enters into a symbolic contractual relationship with older migrants. The obligation for compensatory labour disappeared after 1991.

From 1991 to 1998, the situation changed considerably. In 1991 the institutional arrangement in Ouoghi village became more formal with the establishment of documented land-use rules between the ADESVO and the migrants. The *Balè* lost their prerogatives in land management in favour of ADESVO. The system evolved from a gift-based form to a monetary form (Table 2). The land was still collectively managed by the village association, however, and the rent collected was used for development action in the village. Natives were conscious of their interdependence with the migrants who contributed to the economic development of the area. The early migrants who had stayed in the village for at least 10 to 15 years were considered part of the community and were therefore charged less than newcomers (or even exempted from rent). Migrants were charged more in Boubouhou. In order to harmonise the rent in the whole

Savè area, landowners came together to create an organization representative of the interests of landowners throughout the *Tchabè* area.

From 1999 onwards, in Ouoghi and Boubouhou, the amount of yearly rent to be paid per hectare was fixed. From a legal perspective the tenure systems in both areas were converging, but this was not so in practice. The mechanism behind this apparent convergence was guided by the landowners' desire for a fixed and unified rent throughout the whole area. Due to the fact that the landowners could not readily ascertain the areas cultivated by individual migrants, a minimum area of three hectares was assumed. Therefore, rent is fixed, and does not depend on the actual area cultivated. In Ouoghi, where natives want to attract more migrants, this unit of account is not strictly applied, and migrants usually pay less than the specified amount. The actual amount of rent to be paid is flexible, *i.e.* it is negotiated between the leader (spokesman) of the migrant community and the ADESVO.

With a system where rent is independent of area cultivated, it is rather to be expected that migrants in the Boubouhou area will develop extensive land-use systems (see below). Most of the migrants in Boubouhou area find the fixed rent too high. Quoting the words of a migrant farmer in Kogbogoun: "*We are complaining because soils are getting poorer than in the past, fertile virgin lands are almost gone, and we are obliged to come back to the former fallow lands that do not produce as much [all consistent with the expectation just mentioned]. We suggest to the landowners to diminish the rent. But we do not refuse to pay because the lands belong to the landowners*". Here, then, is the problem in a nutshell – change is needed in a system that places no premium on careful use of land. But it is not clear whether the changes should be technological, institutional, or both. It would be ideal (see below) to create a situation in which technological and institutional changes are mutually supportive.

Strategies developed by migrants to obtain farmland and labour

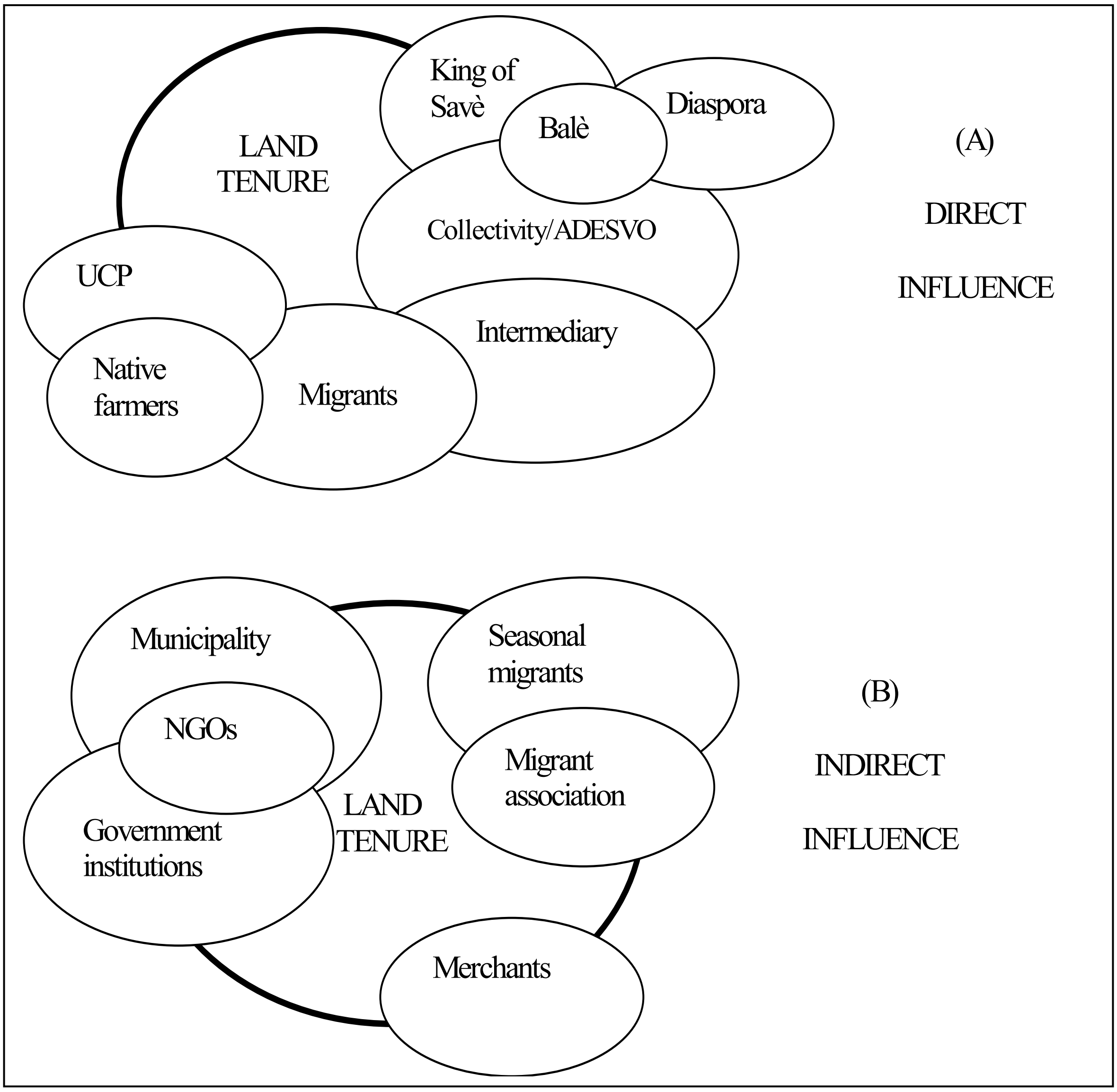
Because the negotiation of the tenurial arrangement between landowners and migrants concerns the men, *i.e.* male heads of the household, we deliberately use masculine gender in this section. In both areas, early migrants have greater tenure security compared to later migrants (from the same region) and thereby increase their relative social power. The early migrants (7% of the respondents) do not pay rent, because they are leaders of the migrants' group. In Boubouhou, when a new migrant arrives in a hamlet, he is not immediately introduced to the collectivity of landowners. He works as labourer for an established migrant who serves as his sponsor for at least one year. Then a piece of uncultivated land is allocated to him. Landowners know this is happening, and they sanction it to some extent. This practice is probably a way to encourage a hierarchy of tenure security in a situation where indigenous people want to convey the message that the area is closed for newcomers. After one cropping season, *i.e.* when the newcomer has accumulated some money, he is then introduced to the collectivity of landowners. Just under half the migrants interviewed (44%) had proceeded in this way, while 46% of migrants were directly introduced to the landowners when they arrived newly in the village. This latter option is profitable for the migrants because they could request uncultivated lands of higher fertility. However, it is beneficial only for those with sufficient money on arrival not to need to first work as labourers.

New migrants with enough money prefer a direct contract with the landowners, because they can pay, whereas poorer new migrants prefer to build up a relation with an older migrant, until sufficient wealth to obtain a tenure contract has been accumulated. Finally 3% of migrants interviewed, particularly those cultivating only a small piece of land, work informally (unseen by landowners), because they have not yet been introduced to the landowners. The landowners do not know those people. When discovered, these migrants are punished or evicted from the area. In the Boubouhou area, old migrants risk eviction as well if they allow new migrants on the land without telling the landowners.

Power relationships in the tenurial arrangement

In our study, careful consideration of relative power relations was essential in order to understand who could, should and would influence alternative tenurial arrangements either positively or negatively. Fig. 2 presents the stakeholders involved in tenure management. In both areas the most important stakeholders directly influencing tenurial arrangements (Fig. 2A) are:

- people from “diaspora” (absentee educated elites now living in the large urban centres, including overseas);
- the traditional power (the *Kabiyesi* [king] of Savè and the *Balè*, his representative at each village level - according to customary rules, the king is the guardian of the land and only members belonging to one of the collectivities of landowners can be elected as *Kabiyesi*);
- the collectivities of landowners (*Omo onilè*);
- the ADESVO and the land management committee (‘*comité de gestion des terres*’);
- intermediaries (spokesmen, usually the early migrants, who serve as leaders for the entire migrant group);
- the migrant groups;
- native farmers (according to customary rules, they are not owners of the land but as indigenous inhabitants they have a usufruct right, *i.e.* they do not pay rent and have greater land security);
- and farmers’ organisations GPC (*Groupement des Producteurs de Coton*) and UCP (*Union Communal des Producteurs*).



Indicates linkage between two groups of stakeholder.

N.B. The size of the circle indicates the relative importance of the stakeholder.

Figure 2. Venn diagram representing (A) the most important stakeholders and their linkage and (B) the stakeholders having an indirect influence on the tenurial management in Boubouhou and Ouoghi village in Benin.

A second group of stakeholders (Fig. 2B) has an indirect influence on the tenurial arrangement. These include:

- government institutions providing services (R&D, CeCPA national extension service, and PDE III project);
- NGOs (CEBEDES and Inter CECO);
- seasonal labouring migrants;
- the Atacora-Donga migrant association;
- merchants;
- the local administration, *i.e.*, the municipality (elected bodies or local councils) representing the state.

In Boubouhou and Ouoghi village, the authority of the traditional powers (the *Kabiyesi* and the *Balè* respectively) on land management has diminished but they are still consulted on issues related to land tenure, *e.g.* conflict management. The absentee elites (diaspora) are still concerned with activities in the village as a consequence of decentralisation. They generally serve as advisors, *i.e.* they are key persons in decision making concerning local development. Although administrative decentralisation was intended to strengthen local management of public affairs (including land management), the elected councils were not granted decision making power on farmlands. They manage only peri-urban land. Nevertheless, they are official stakeholders, in the sense that they must eventually legitimate (in a legal and/or practical sense) any emergent alternative tenure arrangement.

Traders or merchants play an indirect role in tenurial management because they influence prices. The migrants' spokesmen are in effect the landowners' eyes in each hamlet. Without them introducing new migrants to landowners, the landowners are blind. They are thus properly regarded as a key part of the informal customary system. The spokesmen play such a strategic role that their point of view should not be overlooked. Furthermore, spokesmen have vested interests in the existing and any new system in relation to their role in mobilization of labourers, rent exemption, and in keeping part of the rent to be paid to the landowners. To formalise alternative tenurial systems and enhance tenure security for migrants it may be necessary to enhance the local administrative powers in governing such a systems.

In Boubouhou and neighbouring villages studies revealed some important conflicts of interest, and contested power relationships, involving clashes between different collectivities of landowners, between collectivities of landowners and the municipality, between cotton growers and non-cotton growers (migrants growing yam, maize and egusi melon as cash crops), and between landowners in Boubouhou area and the ADESVO in Ouoghi (rent payment in Ouoghi is more flexible and it is managed with greater transparency). In Ouoghi conflicts of interest are evident between elder and younger landowners, and between the traditional power (the *Balè*) and the ADESVO. Older land owners prefer the labour-for-land arrangement, as it was done in the past, because it makes labour available in the village, whereas youths prefer a money-for-land arrangement because it allows them to calculate their costs and is more profitable for the whole community (it provides financial resources for development infrastructure). Flexibility in rent payment creates a social linkage between migrants and natives of Ouoghi. Migrants invest in economic activities in the area, such as running trucks for transportation, building houses, creating shops, etc.

There is discord between the group of landowners from the whole Savè area (the *collectif* of 11 lineage groups, *cf.* Le Meur [2002]) and the Ouoghi village development association (ADESVO). Landowners in the Boubouhou area accuse the ADESVO of giving facilities and favourable conditions to the migrants. The cotton growers' organisation (UCP) wants an increase of cotton production in the area in order to get more money for the development of the locality, whereas landowners discourage the migrants (big cotton producers in the area) by charging them annual rent. Finally, the municipality wants to collect tax on the rent collected by the landowners. The municipality derives its legitimacy from statutory rules because it represents the state. Migrants approve that rent is collected by the municipality because it provides them with more tenure security. As in all formal affairs, this may have to do with the use of paper documents that enhance tenure security. But in the process of decentralisation - in Benin decentralisation is not yet complete in the rural area - the municipality seeks to exert its influence and control over land tenure management, perhaps more as a rent seeking opportunity than for any reason of technological rationality.

Factors enhancing or diminishing mutual trust between landowners and migrants

In both areas, a market in farm land does not yet exist. Land is regarded by the natives as a sacred good inherited from the ancestors and that it cannot be sold to anybody outside the family. In Ouoghi there is not much disagreement on land ownership, since the amount and modality of payment for renting of land is negotiable. In Boubouhou the (ir)regularity of rent payment is the main source of disagreement between migrants and the collectivity of landowners. "*If you cannot pay the rent, you must leave our land!"* is a regular threat, uttered by certain members of the collectivity of landowners to migrants who do not pay the yearly rent on time.

The probit analysis (Table 3) revealed that only the total area cultivated was significantly ($P < 0.05$) correlated with the migrants' capability to pay the yearly rent. Migrants cultivating less than 3 ha were not able to pay, or paid rent in instalments. Migrants cultivating more than 3 ha paid rent all at once. The ability to cultivate more than 3 ha is determined by labour availability, *i.e.* the ability of migrants to mobilise migrant newcomers. This reflects whether a farmer has ready cash or "social capital" (*i.e.* a network of contacts willing to work).

Table 3. Probit results on significant variables affecting migrant ability to pay the yearly rent.

Variable name	Types	Variable description	Estimated coefficient	z	$P > \|z\|$
SURFACE_CULT	Continuous	Total surface cultivated in ha	0.258*	2.25	0.024
CASHCROP_SURF	Continuous	Total surface cultivated in ha for cash crops	-0.106 ns	-0.51	0.610
COTTON_SURFACE	Continuous	Total surface cultivated in ha for cotton	0.273 ns	0.56	0.573
LABOURER	Binary	Use of labourers in the household farm (Yes = 1; No = 0)	-0.120 ns	-0.27	0.789
HOUSEHOLD_ SIZE	Continuous	Number of people in the household even labourers	0.041 ns	0.51	0.609
NUMB_WORKER	Continuous	Number of people working for the household farm	0.041 ns	0.21	0.831
MIGRANT_AGE	Continuous	Migrants' age in years	0.008 ns	0.34	0.730
RESIDENCE	Continuous	Duration of stay in years of the migrants in the area	-0.011 ns	-0.38	0.702
ITINERARY	Binary	Itinerary followed by the migrants when coming in the Savè area (those established in other region before arriving in Savè area = 1; those arriving directly from their home village in the Savè area = 0)	0.177 ns	0.42	0.673
INTERCEPT			-0.767 ns	-0.86	0.391

McFadden R-square = 0.222.

* significant at $P < 0.05$.

Sometimes, early migrants collect money from migrant newcomers without informing the landowners. The landowners are cheated, as they do not get all the money owing to them, while the early migrants improve their financial security to the point where they can cultivate a larger area with the possibility to acquire labourers, though their actions may reflect on their tenure security if they are suspected or found out. The new migrants find these under the table payments a way to get into the community. Such situations arise in most migrant villages. Certain migrants also flout the tenurial rules, and grow cashew which is a tree crop. The migrant at fault may then be threatened, and his cashew plants destroyed, in which case the migrant loses while the landowner does not gain; an alternative is that the cashew trees will be confiscated, in which case the landowner gains money while the migrant loses his investment. It is important to mention here that there is no opportunity for migrants to engage in sharecropping with the landowners when cashew is grown. From 2003 to 2004, in the Boubouhou area, tensions between landowners and migrants increased due to non-payment of rent, leading to the eviction of certain migrants. About 60 persons left for Nigeria, where the tenurial condition were said to be better than in Boubouhou. According to the migrants there are also more fertile lands available and the tenurial conditions are based on sharecropping, or labour-for-land. In Boubouhou, migrants and the collectivity of landowners do not communicate well.

We noticed that cotton cultivation was a strategy developed by migrants to pay rent. Because cotton is a cash crop that brings revenue to the state, it has a well-organised filiere (channel, or chain) with inputs supplied on credit, an effective extension service, a marketing organization, fixed and profitable prices, and functional farmer organisations. Through the list of cotton growers, landowners were always informed about the number of migrants producing cotton, and especially the presence of newcomers in the field. An agreement was established between the landowners and farmers' organisation (UCP and GPC) to subtract the yearly rent from the amount of money earned by each migrant after selling their cotton. The system was successful before the entire cotton filiere collapsed due to world market conditions (*e.g.* subsidised production in USA and China, Sinzogan *et al*., 2006). Nowadays, few migrants still grow cotton. Cotton growers refused to pay the rent through the UCP. At the same time, non-cotton growers claimed to have lower crop yields and low and unpredictable prices in the market. Thus, the number of people paying the rent regularly has diminished, and the amount of money earned by landowners has diminished accordingly. The delay in payment for cotton (Sinzogan *et al*., 2004) has also diminished mutual trust. Difficulties in the cotton sector have had a knock-on effect, in terms of more widespread tensions and suspicions between land owners and tenants, increasing the requirement for mechanisms capable of building sustainable and profitable land use and heightened trust.

Consensus building among stakeholders for sustainable tenure arrangement

In order to solve the different disagreements related to the uncomfortable tenure arrangement in Boubouhou, the stakeholders, especially the landowners, agreed to negotiate with migrants for a better arrangement. This required considering different stakeholders' perceptions and interests. Fig. 3 presents the outputs of the action research leading to a negotiation process

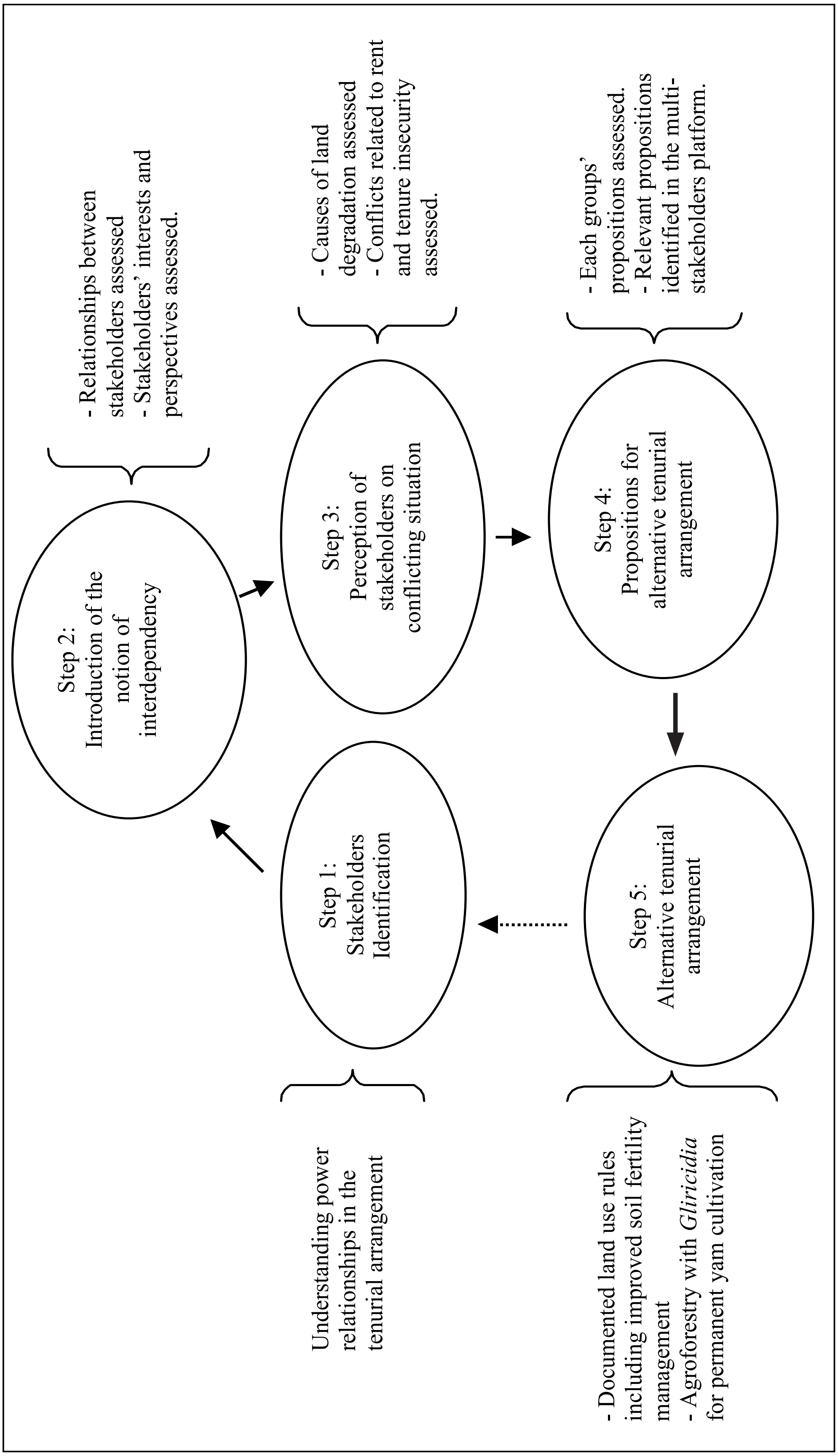


Figure 3. Diagram showing the outcomes and the agreement reached during each step of the negotiation processes for alternative tenurial arrangement.

towards the adoption of consensual land use rules. In order to make people more confident with the alternative contract negotiated the different groups decided that the process should be monitored to make it more transparent.

In Step 1, we started with agreeing that present tenurial arrangements are unfavourable for both migrants and indigenous inhabitants because they lead to land degradation. In Step 2, we facilitated negotiation towards co-ordinated action to accommodate all interests. This step was easy, as all actors recognised that lands were degrading, but began to appear more difficult when they gave different explanations. Landowners attributed land degradation to overexploitation and unsuitable agricultural practices by migrants, whereas migrants believed that tenure insecurity led them to unsustainable agricultural practices (Table 4). All stakeholders were keen to restore soil fertility, or at least to prevent soil degradation. This seemed to provide an opening for technology. The specific question raised for scrutiny was do landowners (especially landowner collectivities in Boubouhou) enable migrants to adopt soil fertility improvement technologies related to yam production.

In Step 3, the stakeholders' perceptions on the old tenurial arrangement and the different conflicting situations (amount of rent, mode of payment, land degradation, non declaration of migrant newcomer, etc.) and their interests were assessed. It was also a starting point to talk about perspectives for sustainable land tenure arrangement. To quote a landowner of the Amushu collectivity: We recognise that migrants are important for our village, they have developed yam and cotton production in our area. In the past, yam was available for only 6 months a year but nowadays one can find yam the whole year long. Even some new yam varieties have been introduced into the area [by migrants]. They have contributed in the creation of the yam market in Savè, instead of selling their products to Glazoué. But they are degrading our lands and some of them refuse to pay the yearly rent.

The economic flux between the village of Ouoghi and the hamlets of the migrants has generated a new source of employment for indigenous women. To quote one such woman from Ouoghi central: *We buy and resell the farm products especially yam, pepper and egusi in Ouoghi and Savè markets. Our men must forget about the rent and facilitate a collaborative atmosphere in order to attract more migrants to the area because they are developing our village. Nowadays there are some women who have taxi moto (Zemidjan).*

In Step 4 participants developed a shared interpretation of the situation reflecting, as far as possible, all perceptions. Various solutions were proposed by the different groups: forsake rent payment, reduce the amount of rent, revert to the former practices (*i.e.* labour-for-land transactions), grant permission for migrants to plant trees (especially cashew), develop documented land use rules, introduce improved land management technologies (re-afforestation of degraded areas, integration of soil fertility improvement technologies in land use rules),

Table 4. Key stakeholders' perceptions on environmental degradation in the Savè region.

Stakeholders	Environmental degradation			
	Causes	Consequences	Responsibilities	Solutions
Native farmers	Deforestation, overexploitation of the land, cropping pattern, bush fires.	Erosion, soil fertility depletion, decrease of crop yield.	Migrants and charcoal producers.	- Improved soil fertility management practices; - Reforestation.
Migrant farmers	Insecure land tenure, increase demand for yam and cotton, wealth (asset).	Soil fertility depletion, crop yield decrease, land scarcity, reduction of fallow period.	Landowners and consumers.	- Durable land tenure arrangement; - Improved soil fertility management practices.
Landowners	Deforestation, charcoal production, destruction of agrarian landscapes by migrant farmers.	Land degradation, lost of biodiversity (wildlife and trees).	Migrants	- Reforestation; - Respect of land use contract.
Extension service	Reduction of fallow period, continuous cultivation, deforestation, weak level of chemical fertiliser use, charcoal production.	Soil fertility depletion, erosion, unsustainable cropping system, decrease of crop yield.	Migrant and native farmers.	- Improved cropping system; - Improved soil fertility management practices.
Researchers	Overexploitation of the farmland, deforestation, non adoption of durable soil fertility management.	Soil fertility depletion, erosion, decrease of crop yield.	Migrant and native farmers.	Adoption of improved soil fertility management technologies.
Municipality	Deforestation, unsuitable cropping system.	Land degradation and crop yield decrease.	Farmers	Improved soil fertility management technologies.

and (finally) engage in collective action (involve farmers' and migrants' organisations in rent collection, regulate crop prices in the market, use rent collected for development action from which migrants can benefit, as in Ouoghi village, etc.).

During the last step of the negotiation process (Step 5), the different propositions were discussed extensively in order to arrive at an agreement. Forsaking or reducing rents and labour-for-land transactions were categorically rejected by landowners. The collectivity of landowners of Boubouhou and neighbouring villages preferred afforestation, not of cashew but of species formerly abundant in the area, such as African mahogany (*Khaya senegalensis*) and Iroko (*Milicia excelsa*) cut down by the migrants. Only the shea-butter tree (*Vitellaria paradoxa*), which produces a vegetable oil, and African locust-bean tree (*Parkia biglobosa*), which is used in the processing of a traditional mustard, were left standing by migrants when they cleared land. As the research and development oriented NGOs, CeCPA and CEBEDES are introducing agroforestry in the area for permanent yam cropping (a project known in French as *sédentarisation de la culture d'igname avec le Gliricidia*), both groups agreed to experiment with that agroforestry technology, since it already has an organised extension service. The permanent yam cropping technology emphasises pruning of *Gliricidia sepium*, a nitrogen-fixing tree planted in rows in the field, creating alleys between which yam is grown. *Gliricidia* can fix nitrogen and its deep roots work as pumps to bring nutrients to the surface. This technology was therefore preferred, whereas *Khaya* and *Milicia* serve only for afforestation purposes, and are not quick-growing. *Khaya* has medicinal properties.

A problem of this type of negotiated arrangement is that it proposes a form of tree planting and hence of land appropriation. Both groups (migrants and land-owners) agreed to specify in documented land use rules that planting trees for land improvement purposes does not mean that land users may claim land ownership. In addition to the permanent yam cropping technology, both groups agreed to promote improved soil fertility management practices such as crop rotation by including legumes in the rotation system instead of cereal-cereal rotation, and crop residue management. These improved land management practices are likely to result in an increase in the duration of land utilisation.

Analysis and Discussion

Tenure insecurity and land degradation: comparative analysis of migrant and native farmers cropping systems

In many regards, the study area is similar to those described by Barbier (1998) and Gray and Kevane (2001) in south-western Burkina Faso and Tiffen *et al*. (1994) in Kenya, where processes of intensification are also underway. With the presence of migrants, cultivated land has increased at the expense of forest. Migrant farmers are blamed by the young indigenous farmers for reduction in fallow periods and soil degradation. Population growth among migrants and increased market demand for certain crops (yam, maize and cotton) have resulted in land scarcity, and consequently reduction of the fallow period. Agricultural intensification was possible due to labour availability, provided by seasonal migrant labourers. This leads to more continuous cultivation, which changes land rights. A subset of wealthier farmers are able easily to pay the yearly rent, thereby securing land rights, whereas poorer farmers have to abandon the land because they cannot sustain cultivation through intensification, with the result that they become less secure in their tenure rights.

This observation seemingly contradicts Boserup's (1965) assumption that intensification of agriculture not only results in higher yields, but also in increasing per capita production across the board. In fact, whether intensification degrades or improves agricultural productivity in the circumstances described depends on labour availability, which in turn reflects the situation of labour opportunities outside agriculture. It is probably wrong to assume that demographic or technological changes lead inevitably to certain land–use outcomes (whether negative or favourable). What the approach above suggests is that specific trade-offs require to be identified through consultation and negotiation. Space is required for consultation and negotiation between different stakeholders around technological and institutional options.

Critical reflection on the contractual basis of sustainable land use agreements

Tenure security is said to be important for technology adoption (Fraser, 2004; Manyong and Houndékon, 2000). Tenure security is a necessary but probably not a sufficient condition. Increasing technology adoption rates also requires other conditions, such as markets for additional output and efficient extension services.

The tenurial arrangement negotiated above consists of the establishment of formal written rules introducing plantation of nitrogen-fixing trees for permanent yam cropping and adoption of improved soil fertility management practices. These practices are likely to increase the productivity of the land compared to previous shifting cultivation cropping system. Documentation serves as a way of establishing that the adoption of new practices is a kind of contract between the various parties. The use of 'pieces of paper' to secure land rights is discussed by Lavigne Delville (2002b) and Chauveau (2003), but in our case, this paper does not refer to 'sales' or other forms of land rights 'transfer'. Nor does it requires public officials to validate the contracts. This document is a *règlement intérieur* for land use approved by both groups and defining each group's rights and engagement. It does not alter the existing balance of power. The alternative tenurial arrangement was reached due to the recognition by both groups of their interdependency.

Dangbégnon (1998) and Ravnborg and del Pilar Guerrero (1999) showed that stakeholders who experience mutual dependence can reach effective agreements about sustainable management of natural resources on which they depend. Nevertheless, some problems remain. The alternative tenurial arrangement negotiated in the above experiment requires collaboration between R&D and extension institutions, both of which face material and financial shortages (Heemskerk and Wennink, 2006). Several soil fertility management technologies are available but one cannot guarantee their wide adoption by migrant and native farmers in central Benin. This is because these technologies imply extra costs, especially in term of labour (Adegbola *et al.*, 2002). Therefore, arrangements negotiated above will be constrained by labour availability. An economic incentive such as rent reduction for those adopting soil fertility management practices would help consolidate the alternative arrangement by lowering costs, but the landowners rejected this proposal.

It seems impossible to go back to the older tenurial arrangement essentially based on land-for-labour transaction. Such practices are irretrievably lost because young migrants believe that there are better opportunities for earning money than hiring themselves out as labourers. Adjei-Nsiah (2006) reports a similar finding for Wenchi, Ghana. The only way is forward. Thus it seems important to make the mutual benefit of better land use management visible to the stakeholders.

Other work undertaken as part of the convergence of sciences project, of which the present study is a part, shows that it is possible to engage farmers' attention in an experimental approach to the evaluation of agro-technology. In principle the monitoring of technologies agreed as part of land tenure contracts could be documented in ways familiar to scientists in presenting their results for wider professional scrutiny. If the labour costs and soil improvement benefits could be more precisely quantified then they could also be fed back into the documented negotiations at the heart of the contractual approach described above. This might be a way to ease the objections of land owners to offering rent rebates for better land management by migrants.

Conclusion

The study of the two tenurial arrangements in Ouoghi and Boubouhou revealed relationships of dominance and dependence among the various groups. Because land is collectively managed in the Ouoghi area, dependency relationships among the actors are minimised. Owners and tenants recognise mutual dependency and cooperate over both land management and community development activities. The study showed that where resources (include land and labour) are managed collectively mutual trust between stakeholders is enhanced.

With this encouraging local example in mind, attempts were made to resolve disagreements related to unsatisfactory tenure arrangements leading to land degradation. Landowners agreed to negotiate novel arrangements with migrants. These negotiations were carried out via community-based and multi-stakeholder platforms. The interdependence between key stakeholders and the scarcity of fertile land for yam cultivation offered favourable conditions for the negotiation process. From the different propositions discussed, the establishment of formal and documented land use rules, including agroforestry with nitrogen-fixing trees for permanent yam production and adoption of improved soil fertility management practices, was agreed by migrants and landowners. Negotiation was much more complicated with landowner collectivities in Boubouhou because they did not want the power relationship between owners and migrants to be changed. In Ouoghi, where land owners and tenants interact and communicate, formalization of modified tenurial arrangement proved easier to achieve. But in both the easier and more difficult cases negotiation seems the way forward. As a modality of conflict resolution, negotiation tends to work where both parties can more readily see their interests in objective terms, and where it can be shown these interests are inter-dependent. The paper proposes some possible ways in which competing claims over land use might be brought to arbitration through documentation of technological innovation by stakeholder parties.

Chapter 8

General Discussion

A. Saïdou

Chapter 8

General Discussion

Poor soil fertility is regarded as the underlying factor limiting productivity in African agriculture (Giller *et al*., 2006). Many technological innovations have been developed in order to manage soil fertility in smallholder farms (Buresh *et al*., 1997; Waddington *et al*., 1998) but these innovations did not generally appear to be successful (Pretty, 1994; Biot *et al*., 1995; Douthwaite *et al*., 2001; Douthwaite, 2002). The very limited adoption of the various technologies, and absence of widespread testing and experimentation by farmers, are disappointing (Giller *et al*., 2006). Reasons underlying the lack of impact of much agricultural research are undoubtedly complex and include, in addition to technical factors (linear approach for transfer of technology), a host of socio-economic and political factors. Technologies aimed at better management of soils should include such complications (*e.g.* tenure insecurity, labour management, market outlet, R&D institutions, etc.) and treat them as inherent attributes of soil systems. On the other hand, a fundamental problem that the scientific community faces nowadays is the lack of integration of local knowledge. The key additional skill component added by the present study was to build upon farmers' capacity to experiment, learn and to become experts in their own situation. Collaboration between farmers and researchers yields ideas about linking beliefs (interpretation) and causal mechanisms with regards to local land management practices, *i.e.* in term of methodological approach used the study links local ideas based on interpretation of signs and signatures to a science-oriented framework based on explanatory mechanisms.

Reconciling farmers' and scientists' knowledge of soil-plant relationship

In the domain of agricultural science it is difficult to work with a sharp boundary between 'people's science' and 'scientists' science'. In fact, knowledge repertoires of the various actors are the result of 'knowledge encounters' entailing a 'fusion of horizons' which are a mix of the local and the scientific. There must be a real coexistence between the different forms of knowledge for sustainable development (Long, 1992). The role of scientists in such a process is to make local knowledge relevant and understandable to development workers. This will offer an opportunity to make use of indigenous statements and interpretations in the search for scientifically measurable data concerning mechanisms of causation (Pawson and Tilley, 1997).

Whether local knowledge systems should be differentiated from scientific knowledge has been a source of debate since Agrawal (1995) argued that attempts to distinguish between indigenous and scientific knowledge are problematic and misguided. The present study does not attempt to validate local knowledge against the standards of science. The emphasis, by contrast, is to try and start from the perspectives of both farmers and scientists and to close any gap there might be through joint experimentation and co-production of new knowledge. This process begins with a thorough exploration of local and scientific soil knowledge. The discussion of local and scientific knowledge is important for several reasons: it both adds to the general body of knowledge about soil fertility in specific locations, and brings out the fact that all knowledge is situated in a context. Farmers may have different classifications related to soil quality than do researchers, and understanding these differences may point to neglected but researchable topics.

Farmers in the central and northern part of Benin articulate their soil quality concerns using concepts related primarily to agricultural production. Both farmers and conventional science use texture and colour characteristics as key indicators for assessing the suitability of the soil (*cf.* Chapter 2). Farmers connected soil colour and texture with fertility because both two criteria provide qualitative information about soil organic matter content. Furthermore, farmers linked vegetation cover (a dense canopy protects the soil and creates a favourable microclimate, which may stimulate soil biological activity) to improved nutrient availability through breakdown of plant material. All of these criteria have been used in the present study to evaluate soil quality. Farmers' own understandings were taken seriously as a starting point for research.

From the study on beliefs, perceptions (cultural acceptance) and understanding of earthworms, we found that farmers are well aware of earthworms in agro-ecosystems (*cf.* Chapters 3). But specifically, their ideas on the relation between earthworm activity and soil fertility are based on correlation rather than on causal mechanisms. Most farmers consider an abundance of surface casts as an indicator for fertile soils. Chemical analysis of surface casts confirmed that casts were richer in nutrients compared to the topsoil. But farmers' terminology of earthworm casts as a kind of vitamin does not necessarily reflect knowledge of a causal role for earthworms in enhancing soil fertility. Therefore, experimenting with earthworm cast material as fertiliser in the framework of a farmer field school (FFS) curriculum could be useful for farmers to discover this connection.

The assessment of farmers' knowledge on the role of mineral fertilisers for plant growth and development revealed that farmers were also aware of direct and residual effects of fertilisers (*cf.* Chapter 5). Growing maize after cotton and benefiting from this residual effect is a strategy developed by farmers to sustain grain production and improve food self-sufficiency.

While farmers had knowledge on the difference between NPK-SB and urea, as applied to cotton, they did not make a difference between residual effects of both fertilisers. Farmers were also not aware of the different workings of the separate nutrients in a compound fertiliser like NPK-SB. Finally, they did not link leaf colour and discolouration to nutrient deficiency. This was especially true for reddish discolorations of leaves, which scientists considered as a sign of phosphorus deficiency (*cf.* Chapters 4 and 5). Yellow leaves were interpreted by scientists as evidence for nitrogen deficiency. While farmers did link dark green leaves with the application of urea, they suggested that the yellow leaves observed on maize were due to moisture deficiency, not to nutrient shortage. In the case of fertiliser application there is room for further joint experimentation. A reductionistic approach in a joint experiment, linking the individual components of a fertiliser to individual signs of plant health, may contribute to more efficient fertiliser use.

Potential of extensive cassava cropping system in soil fertility maintenance

Earthworm cast enrichment was highest on the poorest soils and cast biomass was different between cassava cultivars (*cf.* Chapter 3). Furthermore, farmers claimed that different cassava cultivars have different effects on soil fertility. Therefore, the better cassava works out for soil fertility the less it should be reflected in casts even though cast enrichment could be a sign indicating when and what to crop. Casts were significantly richer in nutrients than the topsoil but the pattern of cast enrichment as a function of inherent soil fertility was variable. These results depend on initial soil conditions and the quality of the food items (Fragoso *et al*., 1997; Hauser and Asawalam, 1998; Norgrove and Hauser, 2000). The main practical result from this study, based on the positive perception that farmers have on earthworms, is that earthworms may form an entry point for the enhancement of biological activity by implementing suitable land practices (*e.g.* crop residue management instead of burning them during land preparation) in the context of low external input. Furthermore, there is a need to enlarge farmers' knowledge on the positive roles of earthworm in the improvement of soil physical (aggregation, stability and porosity) and biological properties. This can be done in effective way through the framework of a FFS curriculum. It will increase farmers' interest and involvement in future experimentation and/or enhance the understanding of underlying mechanisms determining soil health.

Moreover, preliminary observations pointed towards a role for prior cassava in alleviating P stress for subsequent crops (*cf.* Chapter 4). We therefore hypothesised that a possible mechanism was that cassava, a highly mycotrophic crop, may improve phosphorus availability. It has been reported that high mycorrhizal inoculum at the start of the growing season has beneficial effects on the growth and phosphorus uptake of cereals and legumes (Miller, 2000; Goss and De Varennes, 2002). The effect of cassava on subsequent crop yield improvement may be soil type and/or cassava cultivar dependent. Furthermore, on a relative basis the tubers accumulated more K than N and P. One might be tempted to hypothesise that subsequent crops may suffer from K deficiency or that the sustainability of the system may be problematical (especially in soils with small K pools). This item deserves further research in order to look specifically at the K-balance. From the studies of Howeler (2002) and Adjei-Nsiah (2006) it also appeared that other mechanisms may be involved. Cassava can reduce nutrient loss by preventing erosion (due to the canopy type and the amount of leaf biomass) and possibly by suppressing weed seed bank (Adjei-Nsiah, 2006). Hulugalle and Ezumah (1991) mentioned that cassava sole cropping is an efficient strategy to protect the soil against water runoff and soil erosion because its canopy protects the soil surface from the effect of high intensity rainfall.

Leaf litter of cassava is an important source of organic matter and nutrients (Carsky and Toukourou, 2003). Van Noordwijk and Purnomisid (1992) estimated 2 to 2.5 t DM ha^{-1} in Indonesia, and Carsky and Toukourou (2003) estimated 2.0 and 2.8 t DM ha^{-1} (in unamended and fertilised soil) in southern Benin. Saragoni *et al*. (1992) attributed maize yield improvement immediately after a dense stand of cassava in southern Togo to the importance of leaf litter. Data by Adjei-Nsiah (2006) also indicated high maize yields after cassava (comparable to the yields if maize was rotated with nitrogen-fixing legumes). The quality of the litter is quite good (C/N = 30; lignin 22.1%; Saïdou, unpublished). Adjei-Nsiah (2006) reported even higher N content for cassava leaf litter (2.5%, resulting in C/N = 20). Disappearance of cassava litter from litter bags was also rapid, indicating high nitrogen mineralisation potential. Olasantan *et al*. (1996) for example stated that soil available N and exchangeable Ca and Mg in cassava pure stands were greater than those in maize or mixed stands.

In the case of this study, we only tested the differential effects of cassava cultivars on subsequent maize crop yield improvement, but we did not properly test the hypothesis whether cassava improves soil fertility. Our results suggested that judicious choice of cassava cultivars may be useful in maintaining reasonable subsequent crop yield, although a larger number of cassava (with different architectures) need to be tested on a wide range of soils and under a wide range of climatic conditions. This research must also include a better assessment of the long-term effects on the main macronutrients. Phosphorus fractionation in the different soil layers and a study of soil biological properties will be needed to show the role that cassava can play in influencing phosphorus dynamics.

Crop and nutrient management in the traditional cropping system

Crop rotation is one of the strategies implemented by farmers to cope with decline of soil fertility. The crop sequence in the field depends on several factors: soil fertility status, farmers’ skill, food habit and prior experiences especially rainfall and market opportunity. Farmers are aware that good crop years result in more produce on the markets as a consequence of which prices drop. This lower price discourage farmers vis-à-vis this crop, and they reduce the area of land allocated to this crop. Moreover, the land management strategy based on via long-term fallowing is no longer feasible because of scarcity of fertile land. In addition to the scarcity of land, agricultural intensification evolves towards permanent cropping systems (Sauerborn *et al.,* 2000) due to population growth which leads mostly to an increasing food demand. The growing demand for food leads to the need for more productive cropping systems. Now, with the need to develop permanent cropping systems and with environmental considerations being the key to sustainable farming practices, a suitable (useful) crop rotation under the conditions of the poor yielding soils and the financial constraints of the small scale farmers which limits their ability to buy inputs could contribute to food security.

We showed the rationality of farmers to adapt fertiliser practices (mixing NPK-SB and urea, in order to solve problems of labour shortage and fertiliser availability on the market; lowering the NPK-SB dose for financial reasons). By cultivating maize after cotton farmers also obtained residual fertiliser benefits (*cf.* Chapter 5). But the system, from the perspective of good maize yields, is vulnerable. The frequency of cotton in the rotation system was mainly due to its high economic importance (main cash crop in Benin with a well-organised commercialisation channel and input delivery at credit). The crisis in the cotton sector (Sinzogan *et al.,* 2006) will also affect fertiliser availability and prices, thereby necessitating further adaptive actions by farmers who still want to benefit from residual fertiliser effects for the subsequent maize. This experiment also showed that land use types (or the sequence of previously grown crops) affected much more the yield of subsequent maize than the fertiliser application practice. This may be due to the amount and timing of N applied in cotton, crop characteristics (rooting system and nutrient requirement), farmer skills (crop, land and weed management practices), and environmental factors (inherent soil fertility). Based on these results, we suggest that the diversity in land use systems, nutrient stocks in the soil and farm constraints (labour, credit, availability on the market) must be addressed in order to come up with rational fertiliser recommendations which will make fertiliser use more profitable to the farmers. The reduction of leaching and erosion effects and the improvement of nutrient use efficiency can best be performed by promoting crop residue management (integrated nutrient management) through the framework of a FFS curriculum. In this platform, the issue of improving farmers' knowledge on the role of individual nutrients in mineral fertilisers will also have to be addressed in order to achieve better nutrient management in farmers' fields.

Validity of participatory on-farm experimentation in farmers' condition

In the domain of science questions of rigour and generalisability of findings are important for the up-scaling issue where one needs to go from context-specific and location-dependent data to more general accounts. But research that intends to produce agricultural technologies or processes for adoption and adaptation by farmers needs to integrate the best of local and scientific knowledge. The issue of quality of science or rigour has also been at the heart of much debate about knowledge derived from traditional and participatory science (Pretty, 1994; Chambers, 1994; Dick, 1997; McDougall and Braun, 2003). Clearly, classical rigour is not in itself sufficient if the science cannot be transferred into real world complex systems. In traditional researcher-led experiments a limited number of factors are usually tested and then the extrapolation of the results to more complex settings is problematic.

Joint experimentation with farmers is sometimes considered difficult, because farmers are thought unlikely to grasp the statistical issues surrounding experimentation. Researcher-managed experiments in farmer's fields are for that reason preferred because replication is better achieved. The present research, however, showed that genuine and effective experiments can be devised by farmer and scientists, but that it is important to reach agreement on common objectives (*e.g.,* sustain the productivity of land). It is therefore necessary to keep the interactions between farmers and researchers transparent, and maintain trust and communication. Scientific rigour was taken into account in term of standardisation (replicability, objectivity, representativeness, reduction of bias, and statistical significance). However, standardisation may be difficult to reach due to field diversity and differences in farmer management skills which may affect the structure of the field data collected (*cf.* Chapters 4 and 5). However, by only looking at variability as noise that needs to be averaged out through appropriate statistical techniques, variation within and between fields and variation in farmers' skills and practices is neglected. Farmers could for that reason dislike statistics as they do see diversity as important and even promote it for reasons of risk-aversion (De Steenhuijsen Piters, 1995). Therefore, bridging both concepts of variation and variability (desirable diversity versus random noise) in an experimental set up is not always easy.

The research has a further methodological twist. In order both to reach scientific rigour and meet farmers' expectations, explanatory mechanisms and interpretative approaches were combined. In much recent commentary by constructivist sociologists of science on scientific activity these two approaches have been rigorously kept apart. Here we have followed a different path. Explicitly, as advocated by Pawson and Tilley (1997), the thesis has operated with the notion that knowledge acquisition is best organised around the development of realist propositions linking context, mechanisms and outcomes. Interpretation – an aspect of context - can serve as a source of hypotheses about casual mechanisms, verifiable in the end by careful examination of outcomes. All science begins with ideas and assumptions. Brainstorming around testable ideas is the basic business of the scientific task group. What has been attempted here is to make farmers – and their brainstorming of testable propositions – part of the task group.

Is collaborative research by scientists and farmers a route to the democratisation of science?

Sustainable agriculture cannot succeed without the full participation and collective action of rural people (*cf*. Chapter 6). Local groups and indigenous institutions are important for rural and agricultural development. In our study we experimented an approach that included co-research (cooperative experiment) by farmers and scientists and learning by doing for enhancing co-construction of knowledge. Such research should ultimately lead to improved livelihoods as assessed by the various dimensions of capital in the broad sense. In Chapter 6 only two dimensions are discussed, human and social capital, and it is important that at a later stage the other dimensions of capital are evaluated, also over a longer time span. This farmers-extension agent-researcher-led group was perceived as a learning space where participants exchanged knowledge on sustainable land management. The strong point here compared with similar community-led groups is the involvement of local communities and other stakeholders during problem identification, research agenda negotiation, and research implementation. In this process, researchers and farmers engaged on an equal basis in planning, implementing and managing action research, and thus built a platform for seeing science as a source of power to be regulated, like political power, by democratic means.

The output of the approach was the enhancement of both human and social capital, both of which seem important with regard to improving extension and research delivery services. The process yielded a strengthening of local institutional and organisational capacity of farmers, placing them in a better position to manage their resources and community assets. As many states have launched administrative decentralisation programs (Rochegude, 1998; Lavigne Delville, 2003), creating such local farmers' institutions will strength the innovation process with a full involvement of farmers in the research activities and create opportunities for local people to influence the research agenda with regards to soil fertility management. A step forward is to reorganise co-research activities in relation with market conditions, farmer networks and agro-ecological zones. A focus on key commodities, in the context of the participatory approach advocated, might motivate farmers towards greater involvement in co-research, and help build a platform of expectation and demand. Lessons learned from farmer self-evaluation of the co-research process suggests that it is important to develop a critical mass of researchers - especially 'field' researchers – capable of co-learning with farmers. This will contribute to the building of impact-oriented research, knowledge and development of institutions, reflecting the needs of farmers in identifying new avenues of research. The critical mass of researchers and extensionists could be built through the development of curricula for agricultural schools. Finally in the context of Benin, there is a need to promote institutional innovation (incorporation of CoS philosophy and approach into technology development practices, organisational and management routines and into capacity-building practices) in order to make agricultural research and extension more client-oriented and client-driven through effective and efficient participation of farmers and other stakeholders. The diffusion of successful results or issues that need further emphasis in term of improvement of farmer knowledge could best be done through the development of modules for FFS curricula or through the development of discovery learning in agricultural research committees.

Tenure security and sustainable land management

Land not only stands at the centre of agricultural production. It is also a matter of wealth, power and social identity (Shipton and Goheen, 1992). The centrality of land in all dimensions of rural African life means that analysis of land tenure issues includes issues such as land use, efficiency of agricultural production, conflict management mechanisms, power relationships and social position (Lavigne Delville, 2004). African land tenure systems continue to be seen as a major barrier to agricultural development. Economic theories suggest that farmers will be reluctant to invest in insecure land. The present study showed that the older informal tenurial arrangements essentially based on labour-for-land transaction are changed due to the increasing importance of monetary transactions in agriculture and the presence of economic opportunities outside agriculture, which constrain labour availability (*cf.* Chapter 7). This has undermined trust in customary land tenancy, as landowners are tempted to exploit migrants through levying high yearly rents. Moreover, tenurial arrangements based on paying fixed annual rent independent of the surface area to be cultivated, and a growing lack of trust between landowners and migrant farmers, have reduced incentives to improve agricultural lands.

Therefore, sustainable soil fertility management in the transitional zone of Benin, in a context of large migration movement, requires a negotiated intersection between particular technological solutions and institutional dimensions, *i.e.* specific trade-offs require to be identified through consultation and negotiation between the different stakeholders around technological and institutional options. A technology-based win-win incentive structure negotiated to motivate migrants as well as landowners gives expectation of better land management. One alternative explored in this thesis was to try and build into tenurial arrangements formal written rules introducing agroforestry with nitrogen-fixing trees for permanent yam cropping and adoption of improved soil fertility management practices. This attempt to insert technology into a land tenure contract can be compared to attempts in Northern Ghana to insert seed technology improvements into contract farming negotiations, as described by Kudadjie (2006). The success of this outcome requires other conditions such as markets for additional output, labour cost and efficient extension services.

Documentation serves as a kind of contract between the various parties (migrant farmers and landowners). It is not a form of 'transfer' of land rights but defines each group's rights in regard to an engagement around land use, and does not alter the existing balance of ownership. The alternative tenurial arrangement was reached due to the recognition by both groups of their interdependency. Its value lies in making the mutual benefit of better land use management visible to the stakeholders. In principle, the monitoring of technologies agreed as part of land tenure contracts could be documented by scientists. This would be a new and innovative role for scientists in rural development, perhaps comparable to the role of para-legal professionals in other areas of rural dispute resolution. We hope that rural development agencies will become interested in the idea, and in making use of local scientific capacity in this regard.

From the outcome of the present research, we suggest a continuation of the CoS experience based on its achievements (the continuity of farmer research groups and the multi-stakeholder platform for conflict resolution that have been established). Emphasis on institutional issues through commodities (cotton) chain (in the case of Benin) could be an important focus but there is also a need that the next phase of CoS continues to look at food crop issues (credit for fertiliser, organisation of the channel by creating effective marketing chains, more attention by research and extension, etc.). By emphasising on both cotton and food crops, CoS will reach one of the objective of the Millennium Development Goals (UN Millennium Project, 2005) which is food security and poverty alleviation in developing countries.

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Summary

Summary

Soil fertility decline has become a major concern of policy makers world-wide, especially in developing countries. In Benin, nutrient depletion due to the shortening of the fallow period without nutrient replenishment is one of the main causes of the decline of soil productivity. Many technological innovations to solve problems of soil fertility decline have been developed and yet these innovations do not generally appear to have been successful. The main reasons are a lack of fit between proposed techniques and local farming systems and farmer livelihood strategies, limited availability and accessibility of external inputs, lack of market access, tenure insecurity and finally lack of participation by land-users in designing and implementing technologies. The top-down approach, in line with the linear Transfer of Technology (ToT) model, may be an important reason for this lack of success. Instead, farmers adopted their own approaches that in the past resulted in sustainable livelihood practices. This study suggests a strategy of listening to and learning from farmers' own knowledge as a starting point for research aimed at soil improvement. The general approach is based on the idea of seeking convergence between farmers' knowledge and conventional sciences. This often involves trying to make a connection between interpretive and explanatory accounts. The research also rests on the idea of convergence between natural and social sciences (β - γ integration). The study forms part of a larger programme 'Convergence of Sciences: inclusive technology innovation processes for better integrated crop and soil management'. The general objective of my research project was to improve farmers' management practices with regard to soil fertility. The study was carried out in the sub-prefecture ('Commune') of Savè, located in the transitional agro-ecological zone of Benin. Since 1975 there has been an influx in the region of migrants from Atacora-Donga and the Abomey Plateau. There are special problems involved in encouraging migrant farmers to conserve soils, due to their weak land rights. The methodological approach used in this study included a technographic study which explored the innovation landscape, diagnostic studies to make pre-analytical choices explicit, and the designing of joint action research in farmers' condition.

Chapter 2 presents results of the diagnostic study carried out during the cropping season (June-November) 2002 in the Atacora-Donga and Savè zones. The perception of farmers about the causes and consequences of land degradation and corrective actions for sustaining soil fertility, and farmers' criteria and approaches for soil classification and differentiation, were studied. Furthermore, the research tried to arrive at a framework for understanding tenure arrangements. Farmers' indicators for assessing soil quality and fertility are mainly based on the occurrence of specific weeds, soil texture, colour, and hydrological quality, soil workability, and

soil fauna (earthworm casting activity). To cope with the problem of land degradation, farmers have developed strategies and activities that either maintain or enhance crop productivity, or which farmers believe solve productivity problems. These strategies include animal manure, inorganic fertiliser, crop rotation, five years fallow, extensive cropping systems with cassava or egusi melon, and emigration. Land tenure arrangements between landowners and migrant farmers affect soil fertility management. The diagnostic study pointed towards the importance of building mutual trust and the need to experiment with different tenure arrangements. Another issue raised during the diagnostic study was the negotiation of a common framework for joint research. In order to test the validity of farmers' claims, we agreed to investigate the potential of extensive egusi melon and cassava rotations as a means to restore soil fertility and maintain adequate crop yields. We also agreed to test the potential of previous cotton fertiliser on subsequent maize yield improvement. The diagnostic phase ended with the establishment of a community-based Stakeholder Learning Group (SLG) including placing an extension agent in charge of co-research activities. In such a committee the concept of democratisation of science is taken seriously when farmers and researchers engage in research discussions on an equal basis.

Chapter 3 links farmers' perceptions about cassava and egusi melon with soil fertility and analyses the roles of earthworms in these systems. Two joint experiments in extensive cassava (varieties odongbo, Bouaké and Ben 86052) and egusi melon (varieties baa, ugba and Côte d'Ivoire), cowpea and maize cultivation were designed to open a path between farmer interpretations and scientific explanations of earthworm casting activities. Almost all farmers were aware of earthworms, named locally *idjèlè* (soil eater). Natives and migrants were equally knowledgeable, but there were significant gender differences in terms of perception on earthworms. The presence of earthworm casts is used by farmers as an indicator for soil health. Farmers understand casts to be a kind of 'vitamin' indicating good conditions for crop growth. The majority of farmers considered rainfall or soil moisture as the main factor underlying earthworm casting activity. Cast deposition was 8-15 t ha^{-1} in the cassava fields and 4-7 t ha^{-1} in the egusi fields. Within cassava fields casting was significantly higher with variety Ben 86052 than with varieties odongbo and Bouaké. Casts showed significantly higher concentrations of macronutrients than the topsoil. In the cassava fields, cast enrichment with total N and Ca^{2+} was highest in the fields with the lowest fertility, but no specific enrichment in the casts as a function of soil fertility was registered for available P and exchangeable Mg^{2+}. In the egusi melon experiment cast enrichment was highest for available P while no specific cast enrichment was registered for exchangeable Ca^{2+}.

In Chapter 4 we tested farmer claims on the potential of cassava to improve subsequent maize yield. We also tested whether a minimum dose of 100 kg ha^{-1} NPK-SB 14-23-14-5-1 fertiliser applied to subsequently planted maize improves plant performance and affects incidence of arbuscular mycorrhizal fungi (AMF). Cassava cultivar, soil depth and fertiliser input all significantly affected the numbers of AMF spores. Spore numbers were significantly negatively correlated with pH (H_2O), P-Bray1 and total N. These correlations suggest that in the more fertile soils spore numbers (but not fractional colonisation) decline. The cassava cultivars did not significantly change soil chemical properties. However, cassava cultivar, subsequent fertiliser treatment, and farmers' management affected significantly maize grain yield. Fertiliser treatment in these conditions significantly improved maize yield by a factor of 1.5 compared with the unfertilised field. Cassava cultivar, fertiliser treatment and farmers' management significantly affected uptake of N and P. The ratios of nutrient uptake rates indicated that P was the main limiting nutrient. However, N was the most limiting nutrient in the subsequent pot experiment. Fractional colonisation of maize roots by AMF ranged from 23 to 38%. In the non-fertilised pots, fractional maize root colonisation by AMF was significantly correlated with root fresh weight, shoot, and N, P, and K uptake in the shoot. It seems there is some basis to what farmers claim. Mycorrhizal associations may be part of the explanation. Having arrived at an awareness of mycorrhiza via experimentation farmers agreed to call them *a fun n'kin oko lodjè*, which literally means 'plant food provider' in Tchabè, a Yoruba dialect.

In Chapter 5 we investigated farmers' knowledge concerning the role of NPK-SB and urea fertiliser, the effect of prior fertiliser treatments and land use types on soil chemical properties and finally the response of cotton and subsequent maize to fertiliser treatment according to recommended and farmers' practices. Farmers attributed plant growth and development to the contribution of NPK-SB fertiliser, and plant health and yield improvement to urea. However, they did not separate effects of the individual nutrients (N, P, K). Furthermore, farmers were knowledgeable about residual effects of fertiliser. High costs of fertiliser, their limited availability, and lack of labour force farmers to adapt existing fertiliser recommendations to their farming system. Cotton fibre and seed mass ranged between 1.2 to 2.0 t DM ha^{-1}. P-Bray 1 before planting the subsequent maize was significantly affected by fertilisation treatments. The lowest maize yields (0.3-0.4 t DM ha^{-1} and 0.7-1.0 t DM ha^{-1} for grain and stover respectively) were registered in the groundnut-maize-cotton land use system and the highest (2.2-2.5 t DM ha^{-1} and 4.3-4.7 t DM ha^{-1}) in the egusi melon-cotton-cotton system. Cotton yields, soil chemical properties, subsequent maize yields and nutrient uptake were significantly affected by land use type. The N : P ratios of nutrients taken up indicated that P was relatively more limiting in the egusi-cotton-cotton system, whereas N was relatively more limiting in the cassava-maize-cotton system. This result is consistent with the hypothesis that cassava could improve P nutrition of a subsequent crop through mycorrhizal carry-over effects.

Chapter 6 examines the impact of the SLG in terms of two dimensions of sustainable livelihood analysis (human and social capital). The overall approach was a difference design (before and after situation). Negotiation of research agenda, planning, implementing, managing action research and continuous monitoring and evaluation were key steps. Farmers and researchers engaged in a critical dialogue (democratisation of science). In an assessment, 73% of farmers claimed that they participated in the SLG in order to improve their knowledge while 27% attended the forum out of curiosity. There is evidence that co-research activities had improved both human capital (farmers' individual knowledge and capacity building) and the social capital (group dynamic, space for innovation, interaction, negotiation skills, improvement of cropping practice, improvement of social relationships, and information sharing). Farmers' knowledge on the role of N, P and K nutrients and arbuscular mycorrhizal fungi had been highly improved. The co-research process enriched the participatory approach by promoting the co-construction of knowledge. A negotiation process to establish mechanisms of linkage between community and district level institutions is a vital next step for the scaling-up of the co-research process. This scaling up will require considerable investment in human resources, in new educational facilities, and in building quality partnerships for learning and action research. A step forward might be to focus on key (cash-earning) commodities in order to motivate farmers towards greater involvement in the co-research, and help build a platform of expectation and demand, without which research will continue to seem irrelevant to many farmers.

Chapter 7 reports how new forms of trust can be built in order to motivate landowners and migrants to work jointly for fair solutions to problems of soil degradation. We report the result of an intervention to construct win-win scenarios around new technologies, using adoption of best practices as an incentive for offering better tenancy terms, with a role for scientists in helping open up pathways to sustainable management and monitoring of results. Two contrasting tenure arrangement systems occur. The first is found in Ouoghi village, where landowners and villagers are organised around the 'Association de Développement Economique et Social du Village de Ouoghi' (ADESVO). The second is found in Boubouhou, where land tenure is managed by landowner lineages. In both systems, migrants are not allowed to grow trees, for fear that this will strengthen their ownership rights. Originally, migrant farmers were incorporated through a land-for-labour transaction. Nowadays, this practice has changed due to the increasing importance of monetary transactions in agriculture and the presence of economic opportunities outside agriculture, which constrain labour availability. The problem to be overcome is how to change mutual perceptions of tree planting as a covert claim to land ownership, since agroforestry is a potential key to soil fertility maintenance. Formal written-down land use rules,

including adoption of agroforestry with *Gliricidia sepium* for permanent yam production and improved soil management practices were negotiated. This document is a ‘règlement intérieur’ for land use approved by both groups and defining each group’s rights and engagement. It does not alter the existing balance of power. An attempt was made to build soil quality monitoring by scientists into the negotiation process. Finally, it came out that the negotiation tends to work better where both parties can more readily see their interests in objective terms. This is a justification for introducing the experimental approach of Convergence of Sciences into debates about agrarian change.

Samenvatting

Samenvatting

De afname van bodemvruchtbaarheid is een belangrijke grond tot zorg geworden bij beleidsmakers, met name in ontwikkelingslanden. In Benin is de uitputting van de voorraad aan plantenvoedende stoffen, ten gevolge van het korter worden van de periode van braak zonder aanvulling met voedingsstoffen, een van de belangrijkste oorzaken voor de afname van de productiviteit in de landbouw. Verschillende technologische innovaties zijn ontwikkeld om de afname van bodemvruchtbaarheid te beëindigen, maar deze innovaties blijken over het algemeen maar weinig succes te hebben. De voornaamste oorzaken voor dit beperkte succes zijn het niet-aangepast zijn van de voorgestelde technieken aan de plaatselijke landbouwsystemen en de manieren waarop landbouwers in hun levensonderhoud voorzien, de beperkte beschikbaarheid en toegankelijkheid van externe producten zoals kunstmest, gebrekkige toegang tot markten, onzekerheid ten aanzien van landgebruikrechten, en tenslotte het gebrek aan participatie door landgebruikers in het bedenken en uitvoeren van deze technologieën. De top-down benadering, zoals die voorkomt in het lineaire model van technologie-overdracht, is een belangrijke oorzaak voor dit gebrek aan succes. Als alternatief hebben boeren hun eigen praktijken ontwikkeld die in het verleden hebben geleid tot duurzame wijzen van levensonderhoud. Dit proefschrift wil een strategie van luisteren naar en leren van de kennis van boeren een belangrijk vertrekpunt laten zijn voor onderzoek dat zich richt op de verbetering van de bodemvruchtbaarheid. Deze algemene benadering is gebaseerd op de idee van convergentie tussen boerenkennis en conventionele wetenschap. Dit zoeken naar convergentie betreft dikwijls een poging om verbindingen te leggen tussen verschillende soorten beschrijvingen en verklaringen van natuurlijke processen. Het in dit proefschrift beschreven onderzoek is eveneens gebaseerd op de idee van convergentie tussen natuurwetenschappen en sociale wetenschappen (ß-γ integratie). Het proefschrift maakt deel uit van een groter programma “Convergentie van Wetenschappen: brede technologische innovatieprocessen ten behoeve van een beter geïntegreerd beheer van gewas en grond” (CoS). Het algemene doel van dit onderzoek was het verbeteren van boerenpraktijken op het gebied van bodemvruchtbaarheidsbeheer. De studie werd uitgevoerd in de sub-prefectuur van Savè, gelegen in de agro-ecologische overgangszone in Benin. Sinds 1975 is de regio gekenmerkt door grootschalige immigratie vanuit de regio Atacora-Donga en het Abomey Plateau. Vanwege hun zwakke landrechten is het een extra opgave om deze migrant-boeren te bewegen om tot duurzaam bodembeheer over te gaan. De methodologische benadering in dit proefschrift bestond uit een technografische studie die het innovatielandschap bestudeerde; diagnostische studies om zogenoemde pre-analytische keuzes expliciet te maken; en het ontwerpen van gezamenlijk actie-onderzoek onder voor boeren relevante omstandigheden.

In hoofdstuk 2 worden de resultaten van de diagnostische studie gepresenteerd, die werd uitgevoerd gedurende het groeiseizoen (Juni-November) van 2002 in de regio's Atacora-Donga en Savè. De opvattingen van boeren over oorzaken en gevolgen van landdegradatie, herstelmaatregelen voor duurzame bodemvruchtbaarheid, en hun criteria om bodems te herkennen en in te delen, werden bestudeerd. De indicatoren die boeren gebruiken om bodemkwaliteit en bodemvruchtbaarheid vast te stellen zijn voornamelijk gebaseerd op het voorkomen van bepaalde (on-)kruiden, bodemtextuur (zand, klei), kleur (donkerder grond is vruchtbaarder), hydrologische kwaliteit (watervasthoudend vermogen), bewerkbaarheid, en het voorkomen van bodemdieren (regenwormen, met name hun uitwerpselen). Om oplossingen te vinden voor het probleem van landdegradatie hebben boeren strategieën ontwikkeld waarvan ze weten of menen dat die de productiviteit van hun gewassen op peil houden of zelfs verbeteren. Deze strategieën omvatten het gebruik van dierlijke meststoffen, gebruik van kunstmest, vruchtwisseling, braak gedurende vijf jaar, extensieve teeltsystemen met cassave of egusi (watermeloen), en emigratie. Ook werd geprobeerd een theoretisch kader te creëren waarbinnen landgebruikregels konden worden begrepen. Overeenkomsten over landgebruik tussen landeigenaren en migrantenboeren hebben grote invloed op bodemvruchtbaarheidsbeheer. De diagnostische studie wees op het belang van het opbouwen van wederzijds vertrouwen en op de noodzaak te experimenteren met verschillende vormen van landgebruikovereenkomsten. Tijdens de diagnostische studie werd het belang duidelijk van realiseren van een gemeenschappelijk kader voor onderzoek met boeren en wetenschappers. Om de geldigheid te testen van boerenopvattingen over bodemvruchtbaarheidsbeheer, werd overeen gekomen om onderzoek te doen naar de mogelijkheden van vruchtwisseling met egusi of met cassave als een manier om de bodemvruchtbaarheid te herstellen en voldoende opbrengst te handhaven. We kwamen eveneens overeen om onderzoek te doen naar de doorwerking van kunstmest, die in het voorafgaande jaar in katoenvelden was opgebracht, op de maïsopbrengst. De diagnostische fase werd afgesloten met het oprichten van een boerenstudiegroep (SLG). Samen met de ter plaatse aanwezige landbouwvoorlichter werd deze groep verantwoordelijk voor het gemeenschappelijke onderzoek samen met wetenschappers. In zo'n boerenstudiegroep wordt de idee van democratisering van wetenschap serieus genomen, doordat boeren en wetenschappers op gelijkwaardige basis het debat aangaan.

In hoofdstuk 3 werden boerenopvattingen onderzocht over de rol van cassave en egusi in de bodemvruchtbaarheid. Ook werd de rol van regenwormen in deze teeltsystemen geanalyseerd. Twee gemeenschappelijke experimenten in velden met cassave (de rassen odongbo, Bouaké en Ben 86052), egusi (de soorten baa, ugba en Côte d'Ivoire), koeienerwt en maïs werden uitgevoerd om een brug te slaan tussen de manier waarop boeren de activiteit van regenwormen interpreteren en de manier waarop de wetenschap deze verklaart. Bijna alle boeren hadden kennis van regenwormen; deze werden in de locale taal (Tchabè, een dialect van Yoruba) *idjèlè* (grondeter) genoemd. Inheemse boeren en migranten-boeren hadden een vergelijkbaar kennisniveau, maar er waren significante verschillen tussen mannen en vrouwen in hun opvattingen over regenwormen. De aanwezigheid van uitwerpselen van regenwormen wordt door boeren als een indicator voor bodemgezondheid gebruikt. In hun opvattingen zijn die uitwerpselen een soort 'vitamine' die wijzen op goede omstandigheden voor gewasgroei. De meerderheid van de boeren beschouwde de hoeveelheid regen of het vochtgehalte van de bodem als de belangrijkste factor die de activiteit van regenwormen verklaart. De hoeveelheid uitwerpselen bedroeg 8-15 ton per hectare in de velden met cassave, en 4-7 ton in de velden met egusi. Binnen de cassavevelden was de hoeveelheid uitwerpselen significant groter bij het ras Ben 86052 dan bij de rassen odongbo en Bouaké. De uitwerpselen bevatten significant grotere concentraties plantenvoedende stoffen dan de bovenste bodemlaag. Dit effect was groter in minder vruchtbare bodems. In de cassavevelden was dit effect groter voor stikstof en calcium, maar niet voor fosfaat en magnesium, terwijl in de egusivelden dit effect juist groot was voor fosfaat, maar niet voor calcium.

In hoofdstuk 4 onderzochten we de bewering van boeren dat de teelt van cassave de opbrengst van maïs als volggewas verhoogt. We onderzochten tevens het effect van een beperkte kunstmestgift van 100 kg per hectare (met stikstof, fosfaat, kalium, zwavel en boor; NPK-SB) op het volggewas maïs. In beide gevallen (bemeste en onbemeste velden) keken we ook naar het voorkomen van arbusculaire mycorrhiza in de cassave en maïs. Cassaveras, bodemdiepte en de kunstmestgift hadden alle een significant effect op het aantal sporen van mycorrhizaschimmels in de bodem. Er was een significant negatief verband tussen aantallen sporen en zuurgraad, fosfaatbeschikbaarheid en totale stikstofvoorraad. Deze correlaties kunnen er op wijzen dat in de meer vruchtbare bodems het aantal sporen (maar niet de wortelkolonisatie door de schimmel) afneemt. De cassaverassen hadden geen significant verschillend effect op bodemchemische eigenschappen. Maar cassaveras, kunstmestgift en het beheer door afzonderlijke boeren hadden alle een significant effect op de maïsopbrengst. De toepassing van kunstmest leidde tot een 50% hogere maïsopbrengst dan in de onbemeste velden. Cassaveras, kunstmestgift en bodem- en gewasbeheer door afzonderlijke boeren hadden alle een significant effect op de opname van stikstof en fosfaat door maïs. De verhouding tussen opname van stikstof en fosfaat gaf aan dat fosfaat de voornaamste beperkende factor was. Maar in een op de veldproef volgende potproef bleek stikstof de voornaamste beperkende factor te zijn. De kolonisatie van maïswortels door arbusculaire-mycorrhizaschimmels varieerde tussen 23 en 38%. In de onbemeste potten was de wortelkolonisatie van maïs significant gecorreleerd met het versgewicht van wortels en spruit, en met de gehaltes van stikstof, fosfaat en kalium in de bovengrondse delen. Op grond van deze resultaten lijkt het erop dat er enige basis is voor de bewering van boeren dat cassave de bodemvruchtbaarheid kan verbeteren, althans de opbrengst van maïs als volggewas. Arbusculaire mycorrhiza vormt wellicht een deel van de verklaring voor dit effect van cassave. Nadat de boeren via deze proeven kennis hadden gemaakt met (en via de microscoop ook waarnemingen hadden kunnen doen aan) arbusculaire mycorrhiza, kwamen ze overeen mycorrhiza *a fun n'kin oko lodjè* te noemen, d.w.z. voedselverschaffer voor de plant.

In hoofdstuk 5 bestudeerden we de kennis van boeren betreffende de werking van kunstmest (NPK-SB) en ureum. We onderzochten het effect van mestgift en landgebruik op bodemchemische eigenschappen en op de opbrengst van katoen en van maïs als volggewas. Katoenvelden worden bemest, en door daarna deze velden te bestemmen voor maïsteelt, maken boeren gebruik van deze mestgift in het voorafgaande gewas. We onderzochten daarbij zowel de door de landbouwvoorlichting aanbevolen mestgift voor katoen als twee boerenaanpassingen (een lagere gift; het mengen van kunstmest met ureum in plaats van dat na elkaar toe te dienen). De hoge prijs voor kunstmest, de beperkte beschikbaarheid (met name na het uitbreken van een crisis in de nationale katoensector) en het tekort aan arbeidskrachten noodzaken boeren om hun bemestingspraktijk aan te passen. Boeren schreven de groei en ontwikkeling van de plant toe aan NPK-SB kunstmest, en plantengezondheid en opbrengstverhoging aan ureum. Boeren maakten echter geen onderscheid tussen de rol van de afzonderlijke componenten in de meststof (stikstof, fosfaat, kalium). De katoenopbrengst varieerde tussen 1,2 en 2,0 ton droge stof per hectare. Er waren geen verschillen tussen de bemestingspraktijken (ook niet bij het volggewas maïs), waarmee de aanpassingen van de boeren als rationeel beschouwd kunnen worden. De fosfaatbeschikbaarheid, voordat maïs als volggewas werd gezaaid, werd significant beïnvloed door de verschillende vormen van bemesting. De laagste maïsopbrengst (0,3-0,4 ton maïskorrel en 0,7-1,0 ton stro) werd gevonden in het teeltsysteem / de vruchtwisseling aardnoot-maïs-katoen; de hoogste opbrengst (2,2-2,5 ton maïskorrel en 4,3-4,7 ton stro) in de vruchtwisseling egusi-katoen-katoen. Katoenopbrengst, bodemchemische eigenschappen, opbrengst van maïs als volggewas en de nutriëntenopname door maïs werden significant beïnvloed door het teeltsysteem. De verhouding van opgenomen stikstof en fosfaat wees erop dat fosfaat relatief meer beperkend was in het systeem egusi-katoen-katoen, terwijl stikstof relatief meer beperkend was in het systeem cassave-maïs-katoen. Dit resultaat ondersteunt de hypothese dat cassave een positieve bijdrage kan leveren tot de fosfaatbeschikbaarheid via mycorrhiza-effecten op het volggewas.

In hoofdstuk 6 wordt de betekenis van de boerenstudiegroep voor twee dimensies van hun levensonderhoud onderzocht. Dit gebeurde via een methode die bekend staat als de methode van de vijf kapitalen. In deze studie werd gekeken naar menselijk en sociaal kapitaal. De onderzoeksbenadering bestond uit een vergelijking in de tijd van verandering in die kapitalen. In hun beoordeling achteraf stelde 73% van de boeren dat zij deelnamen aan de boerenstudiegroep omdat zij hun kennis wilden verbeteren, terwijl de resterende 27% deelnam vanuit nieuwsgierigheid. Het bleek dat gezamenlijk onderzoek doen zowel het menselijke kapitaal (individuele boerenkennis) als het sociale kapitaal (groepsdynamiek, ruimte voor innovaties, onderhandelingsvaardigheden, betere teeltsystemen, betere sociale verhoudingen, delen van informatie) had vergroot. De kennis van boeren over de afzonderlijke rol van stikstof, fosfaat en kalium, en hun kennis over arbusculaire mycorrhiza was in hun ogen het meeste toegenomen. Het gemeenschappelijke onderzoeksproces heeft de participatieve benadering verrijkt en heeft het gemeenschappelijke genereren van kennis verbeterd. Een essentiële vervolgstap om dit gemeenschappelijke proces op te schalen naar een hoger niveau bestaat uit het starten van onderhandelingen om betere relaties te creëren tussen boeren op dorpsniveau en de instituties op districtsniveau. Voor dit opschalen is een substantiële investering in mensen nodig, in nieuwe onderwijskansen, en in het opbouwen van partnerschappen van hoge kwaliteit voor leren en actie-onderzoek. Dit zal boeren motiveren tot een grotere betrokkenheid bij het gemeenschappelijke onderzoek. Ook zal dit kunnen bijdragen tot het opbouwen van een platform van verwachtingen en behoeften, zonder welks onderzoek vermoedelijk van weinig belang voor boeren zal blijven.

Hoofdstuk 7 beschrijft hoe nieuwe vormen van vertrouwen opgebouwd kunnen worden om landeigenaren en migranten te motiveren tot samenwerking, om zo te komen tot voor beide partijen redelijke oplossingen voor problemen van bodemdegradatie. We beschrijven de resultaten van een interventie om wederzijds voordelige (win-win) scenario's te construeren rondom nieuwe technologieën, door gebruik te maken van de meest effectieve praktijken als een prikkel om te komen tot betere landgebruikovereenkomsten. De rol van de wetenschap bestaat daarbij uit het openen van nieuwe wegen voor duurzaam bodembeheer, en in het monitoren van de gevolgen voor de bodemvruchtbaarheid door het naleven van deze nieuwe overeenkomsten. Twee contrasterende landgebruikovereenkomsten komen in het onderzoeksgebied voor. De eerste wordt gevonden in Ouoghi village, waar landeigenaren en dorpsinwoners (migranten) georganiseerd zijn in de Association de Développement Economique et Social du Village de Ouoghi (ADESVO). De tweede vorm wordt gevonden in Boubouhou, waar de landgebruikovereenkomsten worden geregeld door families van landeigenaren. In beide systemen is het aan migranten niet toegestaan om bomen te planten, omdat het planten van bomen hun rechten op dat land kan creëren of versterken. In het verleden vonden migranten-boeren hun plek in het systeem door hun arbeidskracht te ruilen voor toegang tot land. Deze praktijk is grotendeels verdwenen doordat geldtransacties van toenemend belang zijn geworden in de landbouw. Ook economische mogelijkheden buiten de landbouw, die leiden tot een afnemende beschikbaarheid aan arbeidskrachten in de landbouw, hebben bijgedragen tot verdwijnen van de land-voor-werk overeenkomsten. Het probleem dat overwonnen dient te worden bestaat erin dat we de wederzijdse opvattingen over het planten van bomen als een heimelijke vorm van landtoeëigening moeten wijzigen, omdat agroforestry (landbouwsystemen met stikstofbindende bomen) een sleutel vormt tot het duurzaam behoud van bodemvruchtbaarheid. Formele, schriftelijk vastgelegde landgebruikregels, inclusief regels voor het gebruik van de stikstofbindende boom *Gliricidia sepium* ten behoeve van de permanente yamteelt, kwamen tot stand na onderhandelingen. Deze regels vormen een ‘règlement intérieur’ voor landgebruik, die werd goedgekeurd door beide partijen. Dit document legt de wederzijdse rechten en verplichtingen vast. Het document brengt geen verandering aan in het bestaande machtsevenwicht tussen landeigenaren en migranten. Een poging werd ondernomen om het monitoren van veranderingen in bodemkwaliteit in het onderhandelingsproces in te bouwen. Het bleek dat zulke onderhandelingen een grotere kans op succes hebben wanneer beide partijen hun belangen in objectieve termen kunnen zien. Dit rechtvaardigt het introduceren van een experimentele benadering als die van Convergence of Sciences in debatten over landbouwveranderingen.

Résumé

Résumé

La baisse de la fertilité des sols constitue un problème majeur dans les pays en développement. Au Bénin, la dégradation des sols due à la poussée démographique avec pour conséquence le raccourcissement de la durée des jachères sans autres mesures compensatoires est l'une des causes principales de la baisse de la productivité des sols. De nombreuses innovations technologiques visant à résoudre les problèmes de la baisse de la fertilité des sols ont été développées, puis mises à la disposition des producteurs mais le constat est le faible taux d'adoption de ces pratiques. Les raisons évoquées sont: l'approche 'top-down' avec une faible implication des producteurs dans le processus de génération des technologies, une incompatibilité entre les technologies proposées et les systèmes de production d'une part et les stratégies de bien-être des producteurs d'autre part, la non disponibilité et l'accessibilité limitée aux intrants, le manque de débouché pour les produits agricoles, et finalement l'insécurité foncière. En conséquence, les producteurs adoptent des stratégies individuelles ou collectives de régénération de la fertilité des sols qui s'adaptent parfaitement aux contraintes de leur milieu. La présente étude suggère que l'on soit à l'écoute des producteurs car le développement des technologies alternatives axé sur les connaissances endogènes des producteurs reste le socle pour la gestion durable de la fertilité des sols. L'approche utilisée est basée sur une analyse dichotomique entre les connaissances scientifiques et endogènes en relation avec la gestion des systèmes de production en vue d'une convergence des sciences biologiques et sociales (intégration ß-γ). En effet, l'étude s'insère dans le cadre du programme de recherche 'Convergence des Sciences' pour une gestion intégrée des cultures et du sol. Ce programme vise à lier les perceptions paysannes avec les théories de la science conventionnelle en vue de bâtir de nouveaux modèles de développement des innovations agricoles. L'étude a été conduite dans la commune de Savè située dans la zone agro-écologique de transition du Bénin. Depuis 1975, la zone de Savè est en proie à un afflux des migrants agricoles originaires de l'Atacora-Donga et du plateau d'Abomey; cette situation rend complexe de nos jours la gestion de la tenure foncière avec comme conséquence la dégradation de la fertilité des terres. L'approche méthodologique utilisée comprend une étude technographique qui a fait la cartographie des innovations technologiques, puis identifier les besoins en matière d'innovation; une étude diagnostic qui a permis de rendre plus explicite au niveau local les choix pré-analytiques en matière d'innovations à étudier et enfin la conduite de recherche-actions axées sur les expérimentations participatives en milieu paysan.

Le Chapitre 2 de la thèse présente les principaux résultats de l'étude diagnostique conduite de juin à novembre 2002 dans les départements de l'Atacora et de la Donga et dans

la commune de Savè. La dégradation du sol avec pour conséquence la baisse du rendement des cultures et la tenure foncière ont été identifiées comme contraintes principales entravant la durabilité des systèmes de production. La présence de certaines herbes spécifiques, la texture et la couleur du sol, la facilité à être travaillé et l'activité de la faune édaphique en particulier la présence des terricules de vers de terre sont les indicateurs utilisés par les producteurs pour apprécier la qualité du sol. Plusieurs stratégies locales contribuant au maintien ou à l'accroissement des rendements culturaux ont été inventoriées. Ces stratégies incluent les déjections animales, la fumure inorganique, les rotations/assolements des cultures, les jachères de courte durée (cinq ans), la jachère manioc ou la culture extensive de goussi (*Citrullus* sp. et *Lagenaria* sp.) et l'émigration. L'insécurité foncière empêche les migrants d'investir dans les pratiques de long terme de restauration de la fertilité des sols. Pour une gestion durable de la fertilité des sols, il est suggéré d'établir un climat de confiance mutuelle par l'expérimentation avec les différents groupes d'intérêt pour un arrangement alternatif de tenure foncière prenant en compte les intérêts de chacune des parties (migrants et propriétaires terriens) en présence. Il a été également négocié avec les producteurs des axes de recherche-action visant à concilier les perceptions paysannes et les théories scientifiques sur le potentiel de la jachère manioc, le système de culture goussi et de l'effet résiduel des engrais inorganiques sur les rendements et les exportations de nutriment d'une subséquente culture de maïs. L'étude diagnostique a pris fin avec la constitution d'un groupe villageois de recherche (GVR) comprenant l'agent local de vulgarisation jouant le rôle de facilitateur au côté de l'équipe de recherche. Le GVR a en charge la conduite des activités de co-recherche avec les producteurs. Une attention particulière est portée sur la démocratisation de la science c'est à dire que les producteurs et les chercheurs s'engagent au cours des séances de discussions et d'échanges de connaissance sur les activités de recherche comme des partenaires égaux. La finalité de la constitution d'un tel groupe c'est l'appropriation du processus de recherche et des résultats par les producteurs.

Le Chapitre 3 établit d'une part, le lien mécanique entre la perception paysanne et les résultats de l'expérimentation sur le fonctionnement de la jachère manioc et le système de culture goussi et d'autre part, la régénération de la fertilité des sols et le rôle spécifique des vers de terre. Deux expérimentations en milieu paysan avec une forte implication des membres du GVR sur la jachère manioc (variétés: odongbo, Bouaké et Ben 86052) et le système de culture goussi (variétés: baa, ugba et Côte d'Ivoire), du niébé et du maïs et une enquête villageoise visant à documenter la perception paysanne sur l'activité des vers de terre ont été conduites. La majorité des producteurs reconnaissent l'utilité et le rôle positif des vers de terre localement appelés *idjèlè* (littérairement mangeur de sol). Les populations autochtones et les migrants possèdent des connaissances similaires sur le rôle des vers de terre, mais on note une différence significative entre les hommes et les femmes du point de vue perception sur le rôle des vers de terre dans le recyclage des nutriments. La présence et l'abondance des terricules de vers de terre sont utilisées comme indicateurs par les producteurs pour évaluer la qualité du sol. Les producteurs considèrent les terricules de vers de terre comme un genre de 'vitamine' parce qu'elles sont perçues comme étant plus riches en nutriment que la partie arable du sol. Les précipitations et l'humidité du sol sont perçues comme facteurs fondamentaux induisant l'activité des vers de terre. Par contre, l'état de la fertilité du sol et l'abondance de la litière sont perçus comme facteurs de moindre importance. Les quantités de terricules produites varient entre 8-15 t ha^{-1} au niveau des jachères manioc et 4-7 t ha^{-1} au niveau des parcelles de goussi. L'activité des vers de terre est significativement plus importante au niveau des parcelles de jachère manioc variété Ben 86052 comparativement aux jachères manioc odongbo et Bouaké. La concentration des terricules en nutriments est significativement plus élevée que celle dans la partie arable du sol. Au niveau des parcelles de jachère manioc, l'enrichissement spécifique des terricules en N total et Ca^{2+} échangeable sont plus importants dans les sols pauvres ce qui dénote que la richesse des terricules en ces nutriments ne provient pas de la richesse du sol. Par contre, l'enrichissement spécifique des terricules en P assimilable et Mg^{2+} échangeable dépend de la richesse du sol. Au niveau de l'essai goussi, l'enrichissement spécifique des terricules est le plus important pour le P assimilable tandis que, l'on note un faible enrichissement spécifique des terricules en Ca^{2+} échangeable.

Au niveau du Chapitre 4, nous avons testé les théories paysannes sur le potentiel de la jachère manioc dans l'amélioration des paramètres de rendement d'une subséquente culture de maïs. Nous avons également testé si une dose minimale de 100 kg ha^{-1} d'engrais NPK-SB 14-23-14-5-1 appliquée à une subséquente culture de maïs améliorerait substantiellement les performances du maïs et l'incidence des champignons mycorrhiziens (CM). Les types de jachère manioc, la profondeur de prélèvement du sol et la fumure minérale ont significativement affecté le nombre de spores de CM dans le sol. Le nombre de spores de CM est significativement et négativement corrélé avec le pH (H_2O), le P assimilable et le N total. Ces résultats indiquent que le nombre de spores de CM diminue au niveau des sols plus fertiles mais le taux de colonisation des racines par les spores des CM ne suit pas cette tendance. Les jachères manioc n'ont pas eu d'effets significatifs sur les propriétés chimiques du sol. Cependant, les types de jachère manioc, la fumure minérale, et le mode de gestion du sol affectent significativement le rendement grain de maïs. L'apport de fumure minérale améliore significativement de 1,5 fois le rendement grain de maïs comparativement aux parcelles non fumées. Les types de jachère manioc, l'application de fumure et la pratique culturale du producteur affectent significativement les exportations de N et P. Les rapports des exportations de nutriment indiquent une carence des sols en P tandis que l'on observe une carence en N au niveau de l'essai en pots. Le taux de colonisation des racines fines de maïs par les CM varie entre 23 - 38%. Dans les pots non fumés, le taux de colonisation des racines de maïs par les CM est significativement corrélé avec le poids frais des racines, la biomasse aérienne, et les exportations de N, P et K. En effet, cette contribution des CM explique en partie la perception paysanne sur le potentiel de la jachère manioc dans l'amélioration des rendements et des exportations des cultures subséquentes. Ces résultats ont été discutés avec les membres du GVR. Les producteurs ont décidé d'appeler les mycorrhizes «*a fun n'kin oko lodjè*», qui signifie littéralement en langue locale *Tchabè* (sous-groupe Yoruba) pourvoyeur de nutriment aux cultures.

La perception des producteurs sur le rôle des engrais NPK-SB et urée, les effets des pratiques paysannes de fertilisation du cotonnier et le mode de succession culturale sur les propriétés chimiques du sol et sur les performances du cotonnier et les paramètres de rendement du maïs subséquent ont été analysés dans le Chapitre 5. Les producteurs attribuent la croissance-développement des plantes à la contribution de l'engrais NPK-SB tandis que la 'santé' de la plante et l'amélioration du rendement sont attribuées à l'urée. Cependant, ils ne font pas de distinction entre le rôle spécifique des nutriments N, P, K. Il ressort également de l'étude que les producteurs ont connaissance de l'effet résiduel des engrais inorganiques dans le sol. La non-disponibilité de main d'œuvre et le souci de maximisation des bénéfices contraignent les producteurs à adapter les technologies de restauration des sols à leur système de production. Les rendements moyens de coton (tous les traitements confondus) varient entre 1,2-2,0 t MS ha^{-1}. Le P assimilable avant le semis du maïs subséquent est significativement affecté par les pratiques de fertilisation. Toutes les pratiques de fumure confondues, les rendements de maïs grains et paille les plus faibles (0,3-0,4 t MS ha^{-1} et 0.7-1.0 t MS ha^{-1} respectivement) sont enregistrés au niveau de la succession culturale arachide-maïs-coton et les rendements les plus élevés (2,2-2,5 t MS ha^{-1} et 4.3-4.7 t MS ha^{-1} respectivement) au niveau de la succession culturale goussi-coton-coton. Les rendements de coton, les propriétés chimiques du sol, les rendements du maïs subséquent et les exportations de nutriment dépendent surtout du mode de succession culturale. Les rapports des exportations N : P indiquent que P est relativement déficient au niveau de la succession culturale goussi-coton-coton, tandis que la déficience du sol en N est relativement prononcée au niveau de la succession culturale manioc-maïs-coton. Ces résultats corroborent l'hypothèse relative à la mobilisation du P par la culture du manioc à travers la contribution des CM.

Le Chapitre 6 rapporte les résultats de l'évaluation de l'impact du processus de co-recherche sur le bien-être des membres du GVR. L'approche différentielle (perception avant et après situation) a été adoptée dans le cadre de cette évaluation. La négociation des protocoles de recherche, la planification des activités, l'installation des expérimentations en milieu paysan, et le monitoring et l'évaluation continue sont les étapes principales du processus de co-recherche. Il ressort de l'évaluation que 73% des membres affirment participer aux activités du GVR dans un but purement éducatif (apprentissage et amélioration des connaissances) tandis que 27% participent pour une simple curiosité. Les activités de co-recherche ont eu d'impact uniquement sur le capital humain (perçu par les producteurs en terme de connaissances acquises et de renforcement des capacités) et le capital social (perçu par les producteurs en terme de dynamique de groupe, interaction, aptitude à la négociation, amélioration des pratiques culturales, amélioration des rapports sociaux, échanges d'informations, etc.). Les producteurs reconnaissent avoir acquis des connaissances nouvelles en ce qui concerne le rôle spécifique des nutriments N, P et K et des champignons mycorrhiziens. Cette approche de recherche améliore les approches participatives existantes en valorisant le processus de co-construction des connaissances. Les enseignements tirés de ce processus de recherche recommandent l'établissement d'un mécanisme visant la liaison des institutions au niveau des villages et celles au niveau communal ou régional en vue d'une appropriation de l'approche par les institutions de recherche-développement et de vulgarisation agricole. La mise en application de cette approche nécessitera sans doute un investissement considérable en matière de ressources humaines et le développement de curriculum pour les agents.

Le Chapitre 7 rapporte les résultats du processus de négociation d'un arrangement de gestion foncière durable prenant en compte la diffusion de nouvelles technologies et l'adoption des pratiques durables de gestion de la fertilité des sols. Deux modes de gestion foncière existent dans la zone. La gestion collective observée dans le village de Ouoghi, où des propriétaires terriens et les communautés villageoises sont organisés autour de l'Association de Développement Economique et Social du Village de Ouoghi (ADESVO) et celui en pratique dans la région de Boubouhou, où la gestion foncière est sous le contrôle des collectivités des propriétaires terriens en particulier la collectivité *Amushu*. Dans les deux systèmes, les migrants ne sont pas autorisés à planter des arbres par crainte qu'ils accroissent leur droit de propriété sur les terres. Le mode d'accès à la terre dans les deux régions a évolué d'un arrangement tributaire (terre agricole contre force de travail) vers un système monétaire dû à la monétisation de l'agriculture et l'existence d'opportunités en dehors du secteur agricole. La conséquence immédiate est la non disponibilité de la main-d'œuvre agricole. La question principale qui se pose ici est comment parvenir à changer les perceptions mutuelles sur la plantation d'arbre puisque l'agro-foresterie est la seule opportunité qui s'offre en vue d'une gestion durable de la fertilité des sols? Nous avons amené les deux parties à dialoguer et à accepter de nouvelles

règles écrites régulant le mode d’accès à la terre et incluant l’adoption de l’agro-foresterie avec *Gliricidia sepium* pour la sédentarisation de la culture d’igname et l’adoption des pratiques culturales durables de restauration de la fertilité des sols. L’accord négocié est l’établissement d’un règlement intérieur régissant le mode d’utilisation des terres approuvé par les deux parties et définissant les droits de chaque groupe de même que les engagements pris. Ces nouvelles règles n’affectent pas l’équilibre des forces existant entre migrants et propriétaires terriens mais renforcent la collaboration entre ces deux groupes. Un accent particulier est mis sur la dimension scientifique de l’amélioration des pratiques culturales et le suivi-évaluation des conséquences éventuelles de ces nouvelles règles d’utilisation des terres. Finalement, il ressort que dans les modalités de résolution des conflits, la négociation constitue un puissant moyen à condition que les parties en présence soient véritablement interdépendantes. Ceci est une raison principale pour l’introduction de l’approche expérimentale de Convergence des Sciences dans les débats sur les changements agraires.

The Convergence of Sciences programme[1]

Background

This thesis is the outcome of a project within the programme "*Convergence of Sciences: inclusive technology innovation processes for better integrated crop and soil management*" (CoS). This programme takes off from the observation that West African farmers derive sub-optimal benefit from formal agricultural science. One important reason for the limited contribution of science to poverty alleviation is the conventional, often tacit, linear perspective on the role of science in innovation, i.e. that scientists first discover or reveal objectively true knowledge, applied scientists transform it into the best technical means to increase productivity and resource efficiency, extension then delivers these technical means to the 'ultimate users', and farmers adopt and diffuse the 'innovations'.

In order to find more efficient and effective models for agricultural technology development the CoS programme analysed participatory innovation processes. Efficient and effective are defined in terms of the inclusion of stakeholders in the research project, and of situating the research in the context of the needs and the opportunities of farmers. In this way stakeholders become the owners of the research process. Innovation is considered the emergent property of an interaction among different stakeholders in agricultural development. Depending on the situation, stakeholders might be village women engaged in a local experiment, but they might also comprise stakeholders such as researchers, farmers, (agri)-businessmen and local government agents.

To make science more beneficial for the rural poor, the CoS programme believes that convergence is needed in three dimensions: between natural and social scientists, between societal stakeholders (including farmers), and between institutions. Assumptions made by CoS are that for research to make an impact in sub-Saharan Africa: most farmers have very small windows of opportunities, farmers are innovative, indigenous knowledge is important, there is a high pressure on natural resources, the market for selling surplus is limited, farmers have little political clout, government preys on farmers for revenue, and institutional and policy support is lacking. To allow '*ex-ante* impact assessment' and ensure that agricultural research is designed to suit the opportunities, conditions and preferences of resource-poor farmers, CoS pioneered

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[1] Hounkonnou, D., D.K. Kossou, T.W. Kuyper, C. Leeuwis, P. Richards, N.G. Röling, O.Sakyi-Dawson, and A. van Huis, 2006. Convergence of sciences: the management of agricultural research for small-scale farmers in Benin and Ghana. *Wageningen Journal of Life Sciences (NJAS)*, 53(3/4): 343-367.

a new context-method-outcome configuration[2] using methods of technography and diagnostic studies.

Technographic and diagnostic studies

The technographic studies explored the innovation landscape for six major crops. They were carried out by mixed teams of Beninese and Ghanaian PhD supervisors. The studies looked at the technological histories, markets, institutions, framework conditions, configurations of stakeholders, and other background factors. The main objective of these studies was to try and grasp the context for innovation in the countries in question, including appreciation of limiting as well as enabling factors.

The diagnostic studies were carried out by PhD students from Benin and Ghana. They focused in on groups of farmers in chosen localities, in response to the innovation opportunities defined during the technographic studies. The diagnostic studies tried to identify the type of agricultural research - targeting mechanisms - that would be needed to ensure that outcomes would be grounded in the opportunities and needs of these farmers. Firstly, that not only meant that research needed to be technically sound, but also that its outcomes would work in the context of the small farmers, taking into account issues such as the market, input provision, and transport availability. Secondly, the outcomes also needed to be appropriate in the context of local farming systems determined by issues such as land tenure, labour availability, and gender. Thirdly, farmers also need to be potentially interested in the outcomes taking into account their perceived opportunities, livelihood strategies, cultural inclinations, etc.

The diagnostic studies led to the CoS researchers facilitating communities of practice of farmers, researchers, scientists from national research institutes, local administrators and local chiefs. The research was designed and conducted with farmer members of the local research groups. Their active involvement led to experiments being added, adapted or revised. It also made the researchers aware of the context in which the research was conducted. A full account of the diagnostic studies can be found in a special issue of NJAS[3].

Experimental work with farmers

After completing the diagnostic studies, the PhD students engaged in experiments with farmers on integrated pest and weed management, soil fertility, and crop genetic diversity, in

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[2] See R. Pawson and N. Tilley, 1997. *Realistic evaluation*. London: Sage Publications.

[3] Struik, P.C. and J.F. Wienk (Eds.), 2005. Diagnostic studies: a research phase in the Convergence of Sciences programme. *Wageningen Journal of Life Sciences (NJAS)*, 52 (3/4): 209-448.

each case also taking into account the institutional constraints to livelihoods. They focused on both experimental content and the design of agricultural research for development relevance. Experiments were designed and conducted together with groups of farmers, and involving all stakeholders relevant for the study. The aim was to focus on actual mechanisms of material transformation – control of pests, enhancement of soil fertility, buffering of seed systems – of direct relevance to poverty alleviation among poor or excluded farming groups. The ninth PhD student carried out comparative ‘research on research’ in order to formulate an interactive framework for agricultural science.

Project organization

All students were supervised by both natural and social scientists from the Netherlands and their home countries. In each country, the national coordinator was assisted by a working group from the various institutions that implemented the programme. A project steering committee of directors of the most relevant research and development organizations advised the programme. The CoS programme had a Scientific Coordination Committee of three persons, including the international coordinator from Wageningen University.

CoS had two main donors: the Interdisciplinary Research and Education Fund (INREF) of the Wageningen University in the Netherlands and the Directorate General for International Cooperation (DGIS), Ministry of Foreign Affairs of the Netherlands. Other sponsors were the FAO Global IPM Facility (FAO/GIF), the Netherlands Organization for Scientific Research (NWO), the Wageningen Graduate School Production Ecology and Resource Conservation (PE&RC), the Technical Centre for Agricultural and Rural Cooperation (CTA or ACP-EU), and the Netherlands organization for international cooperation in higher education (NUFFIC). The total funds available to the project were about € 2.2 million.

Curriculum Vitae

Aliou Saïdou was born on 03 July 1964 in Béoumi, Côte d'Ivoire. After 7 years of primary school respectively at 'Ecole Saint Jean Koko de Bouaké' in Côte d'Ivoire and 'Ecole Djaloumon de Savè' in Benin, he went to 'Collège d'Enseignement Général' of Savè and 'Collège d'Enseignement Général 1' of Parakou for high school. He obtained the high school diploma BAC Science & Technique (ST), in Mathematics and Physics in 1984. In 1984-1985, he did his military service at 'Collège d'Enseignement Général de Nikki' where he taught Mathematics and Physics. He passed the competitive examination to enter the Faculty of Agronomic Sciences of University of Abomey Calavi and obtained the 'Diplôme d'Agronomie Générale' in October 1991. He then continued his studies and obtained the 'Diplôme d'Ingénieur Agronome', option crop science, speciality soil science in February 1992. Between March 1992 and July 1998 he worked as research assistant at Benin National Centre of Agro-Pedology (CENAP/INRAB), Benin Environmental Action Plan (PAE), and Laboratory of Applied Ecology (LEA/FSA/UAC) respectively. He got a fellowship from a Dutch project at the Faculty of Agronomic Sciences of Benin National University to attend the 7th international course on soil and plant analysis and data handling organised by the International Agricultural Centre (IAC), Wageningen University and the International Soil Reference Information Centre (ISRIC) from September to December 1996. From January to July 1998, he was appointed as responsible of the North Antenna of Animal Science Research Unit (URZV) of Benin National Research Institute (INRAB) in charge of agriculture-livestock integration research programme. In August 1998, he was admitted to the Soil and Water programme of Wageningen University under NFP fellowship to pursue a Master of Science degree in the Department of Soil Science and Plant Nutrition (now Soil Quality Department). He earned his Master of Science in Soil Fertility and Plant Nutrition in January 2000 and returned to Benin. From January to September 2001 he was appointed as Chief of environment division of livestock development project (PDE III) under Ministry of Agriculture, Livestock and Fisheries (MAEP). He joined the Convergence of Sciences (CoS) project in October 2001 as PhD sandwich student of Wageningen University at the Sub-department of Soil Quality and the Technology and Agrarian Development (TAO) Group. Aliou Saïdou also holds a Certificate on laboratory management from IAC/WU/ISRIC in December 1996 and a certificate on multi-stakeholder processes from IAC in April 2004. He can be reached at: saidoualiou@gmail.com or saidou.aliou@lycos.com.

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