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Intensification scenarios in south-western Niger: Implications for revisiting fertilizer policy

Roberto La Rovere [a,*,1], Herman Keulen van [b], Pierre Hiernaux [c], Judit Szonyi [d], Robert A. Schipper [e]

[a] International Centre for Wheat and Maize Improvement (CIMMYT), Apdo. Postal 6-641, 06600 Mexico, D.F., Mexico
[b] Plant Research International, and Plant Production Systems Group, Wageningen University and Research Centre, The Netherlands
[c] CESBIO (Centre d'Etudes Spatiales de la Biosphère), Toulouse, France
[d] International Centre for Wheat and Maize Improvement (CIMMYT), Mexico
[e] Development Economics Group, Wageningen University, Wageningen, The Netherlands

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Abstract

In semi-arid south-western Niger, external fertilizer inputs are a complement of livestock-mediated nutrient transfers for maintaining soil fertility. This paper discusses scenarios of intensification for different farm household types in an area representative of the wetter parts of semi-arid Sahel. Twenty-five-year projections suggest that soil fertility may not always or irreversibly deteriorate under intensification, and that nitrogen is the main external input required. Owning animals allows some households to achieve food security and maintain soil fertility by capturing and mobilizing soil nutrients. Intensification will bring various benefits to livelihoods, but these will be unevenly distributed. The results of this paper should caution scientists and policy-makers against the often heard warning of inevitable losses in soil fertility in the Sahel associated with intensive technologies, and against extrapolating conclusions attained at specific locations or social groups. Endogenous coping strategies based on using local inputs can also be effective and should be explored in addition to a continued attention for the need for more targeted uses of external inputs.

Keywords: Intensification; Sahel; Niger; Soil fertility; Fertilizer policy; Crop-livestock

Introduction

The Sahelian part of Niger ranks among the poorest in the world (FAO, 2000). The rural economy is characterized by a low production potential, uncertainty due to water scarcity, low and declining soil fertility (Buerkert et al., 2002), inadequate infrastructure and marketing. Food production is mainly for farm consumption. While most people (81%) live in the rural areas, 21% of the Gross National Product originates from the agricultural sector and 13% from the livestock sector, a main source of exports. The study area is in south-western Niger, with 450 mm annual average rainfall in the June–September season. The area has homogeneous geological characteristics, but land use history, human and animal population density and cropping intensity vary within the region (Hiernaux et al., 1997). Steady population growth and a rapidly rising demand for food has forced Sahelian farmers to expand arable farming and shorten fallow periods, affecting the local agro-environment and development of the area and leading to a decline in crop yields, also due to the poor natural soil fertility and low levels of purchased inputs (Shapiro and Sanders, 1998; Schlecht et al., 2004). Until the 1960s, the increasing food requirements could be met by

* Corresponding author. Tel.: +52 55 58042004x2119; fax: +52 55 58047558.
E-mail address: r.larovere@cgiar.org (R. La Rovere).
[1] Address: CIMMYT, Int., C.I.P./Mexico, A.P. 370, PO Box 60326, Houston, TX 77205, USA.

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expansion of cropland and increases in livestock numbers, but gradually cropland expanded to marginal areas that were either less fertile or more sensitive to soil mining and erosion. The reduction in rangeland and fallows has increasingly limited the availability, quality and accessibility of forages and constrained animal production.

Local farming systems are based on millet, sorghum, legume intercrops and mixed cattle–sheep–goat husbandry and are characterized by communal management of common-pool grazing resources, i.e. rangelands, fallows, crop residues. Pastoralism and mixed crop–livestock farming co-exist in the area. Recently, farmers have increased herd sizes and pastoralists their cropped areas. Crop-livestock integration uses crop residues as feed to maintain part of the herd during the dry season and obtain manure and urine for soil fertility maintenance from own and passing herds. In these systems, animals mediate the spatial and temporal transfer of nutrients from grazed to cultivated fields, and from areas of lower returns from cropping to those with higher returns, thus accelerating nutrient turnover and reducing nutrient loss (Achard and Banoin, 2003).

Population pressure and intensification

Population pressure, heterogeneity in economic conditions of different farms, increasing cropping intensity from expansion of cultivated area, and varying intensification patterns characterize local systems. Population pressure is believed to lead to less fallow and less communal rangelands, and to intensification (Boserup, 1983). At low population pressure, specialized farming systems (cropping, pastoralism) are attractive and fallows maintain the soil fertility. As population increases, farmers look for alternative input sources to maintain soil fertility, thus crop-livestock integration gains in importance. With further pressure, leading to expansion of cropland and reduction in rangeland area, animals rely more on crop residues as sources of feeds. Intensification – as discussed in this paper – involves shorter fallows, increasing levels of labor, draught power, fertilizer and manure use, soil conservation measures, crop residue management practices, livestock feeding and selling strategies, and use of new technologies. Intensification can generally be seen as a continuum, as farmers intensify first using traditional inputs (traditional seed, labor, manure) because of their low capital requirement, and gradually turn to modern inputs (inorganic fertilizer, improved seeds and pesticides) only when they have exhausted their traditional methods (De Ridder et al., 2004; Abdoulaye and Lowenberg-DeBoer, 2000). Many authors have advocated intensification as the only solution for Sahelian systems (e.g. Abdoulaye and Lowenberg-DeBoer, 2000; Reardon et al., 1997). Policy debates have until recently identified reliance on external mineral fertilizer inputs as the solution to support intensification in the Sahel (McIntire and Powell, 1995; Larson and Frisvold, 1996; Breman et al., 2001). At the same time, however, policy reforms have eliminated many public agricultural programs that supported input markets, creating a vacuum that has not yet been filled by the private sector. Hence, most Sahelian farmers now face more difficult access to inputs and higher costs than ever (Reardon et al., 1997).

Objectives

The study explores the implications of population pressure and increasing intensification for fertilizer policy in West Africa, with reference to an area of Niger that represents a large part of the wetter zone of semi-arid agro-pastoral southern Sahel, and discusses the impact on farmers' livelihoods and food security, which are related to the sustenance of soil fertility and land productivity, labor and migration dynamics, and the environment.

Study approach and data

The database constructed by a research project of the International Livestock Research Institute (ILRI) in Niger was used as the primary data source for this study. This database covers villages situated within a 500 km^2 radius in the Fakara area, located between 13.6°–13.3°N and 2.5°–2.9°E, comprising nearly 500 households. The area is representative for the wetter agro-pastoral part of the semi-arid Sahel. Despite the vicinity of the capital Niamey, relative soil poverty partially explains the low human population density. The cohabitation of Djerma farmers and Fulani sedentary agro-pastoralists is also representative of many areas in the Sahel.

The study used data generation tools (TCG, Hengsdijk et al., 1998) to derive technically efficient bio-physical coefficients from technical parameters for agricultural activities, to calibrate the model. The model was also fed with primary socio-economic field survey data gathered at research and government institutions and from farmers and pastoralists.

The following operational concepts were employed:

- Livestock activities were defined on the basis of both energy intake levels (feeding strategies) and production objectives (selling strategies). In defining the parameters, intensive systems are the less-mobile ones, extensive systems are the more-mobile ones.
- Feeds were classified in quality categories based on the energy intake level they can maintain, and on seasonal availability.
- Current cropping activities describe actual production systems based on survey data.
- Alternative activities represent feasible production systems not yet widely adopted.
- In the simulations, fallows were considered to perform dual roles: to restore fertility and as sources of animal feeds, so to take into account their roles in the replenishment of organic matter and nutrients at the simulated cropping intensities and (non-additively) as major sources of biomass for grazing. A widely accepted

Table 1
Farm household types, south-western Niger (ILRI data; La Rovere et al., 2005)

Variable	Units	Farm types				
		Camp poor	Camp rich	Village manager	Village poor	Village rich
Family size	Person	9.60	9.59	15.59	8.79	8.27
Sample size (households)	*n*	92	74	27	213	126
Total persons per group	Person	883	710	421	1872	1017
Percent of total population	%	18%	15%	9%	38%	20%
Owned herd size	TLU[a]	5.54	15.48	11.2	1.37	0.96
Animal traction: animals	Head	2.49	3.53	2.25	0.58	0.47
Animal traction: carts	Units	0.04	0.03	0.56	0.00	0.00
Labor availability (human)	Adults	5.84	5.43	8.38	4.94	4.53
Cropland availability	Ha	8.71	12.66	25.24	9.06	21.38
Annual income/capita	CFA	38173	71012	66530	36181	97979

[a] TLU, tropical livestock unit, equivalent to a live weight of 250 kg.

notion in the Sahel is that while crop growth is limited by moisture and nutrient [nitrogen (N), phosphorus (P)] deficits, since most soils are sandy, yields ultimately depend on P availability (Muehlig-Versen et al., 2003). Fertility status was calculated for soil organic matter (SOM), P and N. Rainfall variability is represented by a 10% probability parameter of the known frequency of good and bad years based on historical time series data. Spatial variability in cropping intensity is represented by different sites in the study area, hereafter referred to as communities.[2] These sites are similar in the geomorphology and ecological conditions, but differ in their cropping intensity. A set of intensification levels combine diverse management strategies (see La Rovere et al., 2005); these range from the very extensive (long fallow, no manure use), to extensive (long /short fallow, very low draught power use), semi-intensive (short/no fallow, limited manure, tillage and fertilizer use, low draught power use), intensive (short/fallow, plain soil conservation, mineral fertilizer use), up to the very intensive (no fallow, intensive manure and fertilizer use, advanced soil conservation, draught power use). Similar concepts were used for intensity of livestock feeding and selling strategies.

Representative farm types were stratified based on their endowments in productive asset (Table 1): labor, livestock, equipment, and land. The study covered the local Djerma and Fulani communities. They both live in the same agro-ecosystem but have different means of production, access rights to resources, and production objectives. The Fulani reside in camps, move in a short radius around the village, are shifting to arable farming, but have no land rights. The Djerma village households hold traditional land rights, but own few animals. Some of the larger village households own animals. The typology comprises the:

- Fairly livestock-endowed, but land-scarce *camp poor* agro-pastoralists.
- Highly livestock-endowed *camp rich* agro-pastoralists.
- Land- and animal-endowed and larger (family size) *village managers*.
- Livestock-poor and average land-endowed *village poor*.
- Land-endowed, but livestock-poor *village rich*.

The total population of the area surveyed is about 5000 people, with just above 30% of people living in camps and 70% residing in the villages. The largest group is that of the village poor (38%), while the camp poor are 18%. The poorer farms thus constitute more than half of all farms. Income per capita derived from the survey is given in Table 1.

The annual food consumption requirement to ensure human nutritional security was set to 280 kg of cereal grain equivalents per adult male equivalent (FAO, 2000), in part being covered by meat (18.25 kg) and milk (49 kg). A 3% annual increase in human population was used. Herd growth data from the Ministry of Agriculture and Livestock were used in the model simulations. ILRI survey and key-informant data included price and yield time series data for cereals, legumes, and crop residues; migration rates for different household types, wages (fixed in the model),[3] seasonal labor availability and demand; production inputs (fertilizers, equipment, draught power, veterinary care, and supplements) and outputs (meat and milk, animals); transaction and transport costs (through a cost-route approach to the closest markets), living costs and average expenditures. ILRI spatial data were used to define seasonal migration patterns, whose driving forces and intensities varied among agro-pastoralists and villagers. Farm incomes were derived from sales,

[2] Aerial photographs from the International Center for Research in the Semi-Arid Tropics (ICRISAT) in Niamey, Niger, from the 1950s up to the early 2000s document visually the process of intensification and farming pressure in the area and the likelihood for this to continue on the remaining available lands.

[3] In reality labor movements occur towards farms with labor deficits, if they can pay higher wages.

ownership of livestock, increases in animal and grain stocks and off-farm labor. Annual minimum subsistence income (90,000 CFA[4]/capita) was set as a proxy of monetized nutritional requirements at market prices, plus a premium and customary expenses to meet social obligations; 40,000 CFA/capita is the minimum to meet the basic consumption needs. An inflation rate of 4% (FAO, 2000) was used to discount future income levels and prices.

Methods

The study consisted of explorative (Van Ittersum et al., 1998) recursive (Barbier, 1999) bio-economic optimization models (Kruseman and Bade, 1998). These assume that farm households maximize each year a utility function. This function (from Sissoko, 1998) represents household utility as the weighted sum of utility deriving from consumption and income, standardized by their maximum values (Kruseman and Bade, 1998). The weights (Sissoko, 1998, based on empirical data for Mali) and shape of the utility function were exogenous. The model runs 25-year forward-looking scenarios to simulate the hypothesis of continuing steady population growth leading to increased pressure on the land and the changes that would occur in farm household livelihood indicators. The initial data refers to the 1997 baseline year. The static model of La Rovere et al. (2005) form the basis for the present study, which simulates the temporal, additive, and non-linear interactions between the components of the system. The situations explored range from those currently encountered at the study sites, to future situations determined by assuming intensification of management, higher cropping intensity, and sustained human and animal population pressure. Various resources (land area, labor, livestock feeds, pasture, etc.) are locally in limited supply, seasonally not available, not accessible, or can only be obtained from outside the system and constitute farm or community constraints. In the recursive model, resources cumulate into end-of-year stocks that form initial stocks for the next year. These resources may become scarce, so their marginal values increase as they reach critical thresholds where the effect of their scarcity cumulates over time and in turn can feedback on the system. This paper specifically simulates the feedbacks of:

- Soil fertility: impacts of livestock-mediated soil nutrient transfers on crop yields, and the consequences for marketable farm production and food availability.
- Socio-economic livelihood indicators of income, labor and migration: particularly the impacts of food and economic insecurity and unemployment on migration.

[4] In January 1999, US $ 1 = CFA 560.

Use of grazing resources

Access to available fallows and rangelands for each farm type was set proportional to the farm's relative share in the total managed livestock population. Access to crop residues was open and they were consumed in proportion to the size of the passing herds. Total grazing area was set to the sum of fallows, rangelands and a fraction of the millet cropped area. Based on ILRI data, it was assumed that animals deposit half of their faeces and urine at the corralling spot, and the other half along grazing trails and watering and resting points, in proportion to grazing time and forage availability. The initial cropping intensity was set to 60% of the cultivable land, to represent – based on ILRI survey data and expert knowledge – the current dominant semi-extensive local systems. Expansion of cropland at the expense of marginal or fallow lands was set to 1.5% annually (Hiernaux et al., 1997). Sensitivity analysis indicates that cropland does not exceed – over the 25-year projection horizon – the available community arable area.

Changes in soil fertility status, yields, and in crop production potentials

There is evidence that, in the long-term, soil nutrient mining leads to declining soil fertility (Smaling and Toulmin, 2000; Buerkert et al., 2002), thus affecting future production potentials and yields. In the model it was assumed that yields were negatively related to soil fertility losses in preceding years, based on endogenously generated cumulative nutrient balances. Nutrient balances (BILAN) were defined for each element, per each crop (c), soil type (s), and management type as the difference between annual nutrient availability (AVFERT) and requirements (RQNUTR). Negative balances represent nutrient-deficient situations. Liebig's Law of the minimum was assumed to hold with reference to phosphorus (P), the most limiting nutrient in Sahelian agro-ecosystems (Penning de Vries and Djiteye, 1982). This approach assumes absence of substitutability between nutrients, since they have different functions in the plant growth process. The interactions of macronutrients, their dynamics in the soil, and the multi-annual character of the P investment, were captured in the TCG. The initial stocks of available nutrients were also calculated by the TCG. Sources of nutrients were manure and urine, non-grazed crop residues, fallows and inorganic fertilizers, if locally available and affordable. Recursive processes are typically non-linear; when they occur, endogenous response functions feedback on optimal crop production, land use and other variables. When nutrient balances became negative, an endogenous yield reduction function (QCLOSTP) is activated that describes the effects of P deficits (*effphosd*) on yield. P deficit is calculated as the ratio of cumulative [bilany_{y+1}] nutrient stocks over the nutrients required [RQNUTR] to reach target yields, where bilany_{y+1} is the sum of current annual [BILAN_{y+1}] and past cumulative [bilan_y] nutrient balances:

$$\mathrm{BILAN}_{s,f,y+1} = \mathrm{AVFERT}_{s,f,y+1} - \mathrm{RQNUTR}_{s,f,y+1} \quad (1)$$

$$\mathrm{bilany}_{s,\text{`}P\text{'},y+1} = \mathrm{bilany}_{s,\text{`}P\text{'},y} + \mathrm{BILAN}_{s,\text{`}P\text{'},y+1} \quad (2)$$

$$\mathrm{effphosds}_{y+1} = -\mathrm{bilany}_{s,\text{`}P\text{'},y+1}/\mathrm{RQNUTR}_{s,\text{`}p\text{'}y+1} \quad (3)$$

$$\mathrm{QCLOSTP}_{c,s} = \mathrm{effphosds} \times \frac{QC_{c,s}}{100}, \quad \text{if and when } \mathrm{BILAN}_{S\text{“}P\text{”}} < 0 \quad (4)$$

Attainable crop production [QC] was derived from attainable yields [yield] and defined as a function of applied [*m*] management (La Rovere et al., 2005) and optimal annual land use [LANDUSE]. Annual actual crop production [QCy] was then calculated from attainable crop production, corrected for the effect of phosphorus deficiency [QCLOSTP] on yields, *when* (time) and *where* (soils and land units) those deficits occurred:

$$\mathrm{QC}_{c,s} = \sum_{M} \mathrm{yield}_{c,s,m} \times \mathrm{LANDUSE}_{c,s,m} \quad (5)$$

$$\mathrm{QCy}_{c,s} = \mathrm{QC}_{c,s} \times \mathrm{QCLOSTP}_{c,s} \quad (6)$$

Seasonal changes in employment and migration

Although in reality migration is a very complex process, the decision to migrate is often driven by an assessment of the adequacy of income and food availability in meeting the household sustenance needs (cfr. Barbier, 1999). In the model, seasonal [p] farm labor balance [LABBAL_p] is given by availability [LABAV_p] minus requirement [LABRQ_p]. LABRQ_p is optimized by the model and must be satisfied, particularly at peak times:

$$\mathrm{LABBAL}_p = \mathrm{LABAV}_p - \mathrm{LABRQ}_p \quad (7)$$

Each year a deficit or surplus of labor availability can occur. Each year labor availability [LABAV_p] is also adjusted by population growth [popg] and annual migration [EMIG_p]:

$$\mathrm{LABAV}_p = \mathrm{popg} \times \mathrm{dmf}_p - \mathrm{EMIG}_p \quad (8)$$

dmf_p is the labor available that in each iteration (year) takes the value of labor availability calculated from the previous year. Seasonal migration is a fraction [emigrate] of farm labor availability [LABAV_p]. Additional migration is induced *if* and *when* income per capita [INCAPYC] and consumption [CONCAPY] fall below a threshold [respectively targinc and consreq] and *if* farm households face seasonal labor surpluses.

$$\mathrm{EMIG}_p = \mathrm{emigrate} \times \mathrm{LABAV}_p$$
$$\textbf{if } \mathrm{INCAPYC} < \mathrm{targinc\ AND\ CONCAPY} < \mathrm{consreq\ AND\ LABBAL}_p > 0 \quad (9)$$

Gender and age of the labor force were considered in the calculation of labor balances; in reality those who migrate for seasonal labor are mostly the adult males. Total annual induced migration [EMIGT] feedbacks on farm household population [*POP*], indirectly on food demand as well as on other variables (with famsize being the people on-farm).

$$\mathrm{POP\text{-}EMIGT} = \mathrm{popg} \times \mathrm{famsize} \quad (10)$$

Results

Impacts of cropping intensity and management options on soil fertility

The static results of La Rovere et al. (2005) indicated that increasing cropping intensity generally results in declining soil fertility, and intensification leads to stable or improved organic matter and P balances, but less favorable N status. N balances are negative for most farms, especially for the villagers, and tend to worsen at higher cropping intensities and with intensification. P balances are slightly negative at current forms of management, except for the village rich farms, and generally tend to improve with intensification.

The recursive projections of this study (Fig. 1) show that, with current management, in the long run N status improves slightly and stabilizes after about 18 years (although at negative values). Afterwards, it deteriorates for village rich farms, due to the reduced area intercropped with millet and the N-fixing cowpea. With intensification, main drops in N status occur after 14 years for the camp rich farms and after about 18–20 years for the poorer farms due to land use changes and reduction in cowpea areas. After these changes, N statuses start recovering again due to the reintroduction of cowpea and other legumes.

Future total P balances of most farms remain fairly stable, regardless of the intensity of management. With intensification, P balances of the village managers stay positive, while those of the camp farms attain negative values. The camp rich after 15 years introduce alternative land uses and forms of management that improve P balances. Yield declines driven by negative P balances and by the resulting unfavorable soil P status did not affect much the livestock-endowed farms, but influenced more significantly the other farms.

Impacts of cropping intensity and management options on food production

With intensification, crop production on all farms strongly increases. The village poor farms benefit relatively less than the other farms, yet they also considerably improve their food and nutritional security. Increases in cowpea production alleviate the soil N deficits through increased N fixation. Despite total crop production increases, partially as a result of cropland expansion, on-farm cereal production not always meets the annual per capita consumption requirements. This holds particularly for the camp poor farms (217 kg) and the village poor farms (225 kg). Furthermore, per capita long-term real crop production of the village poor farms decreases with

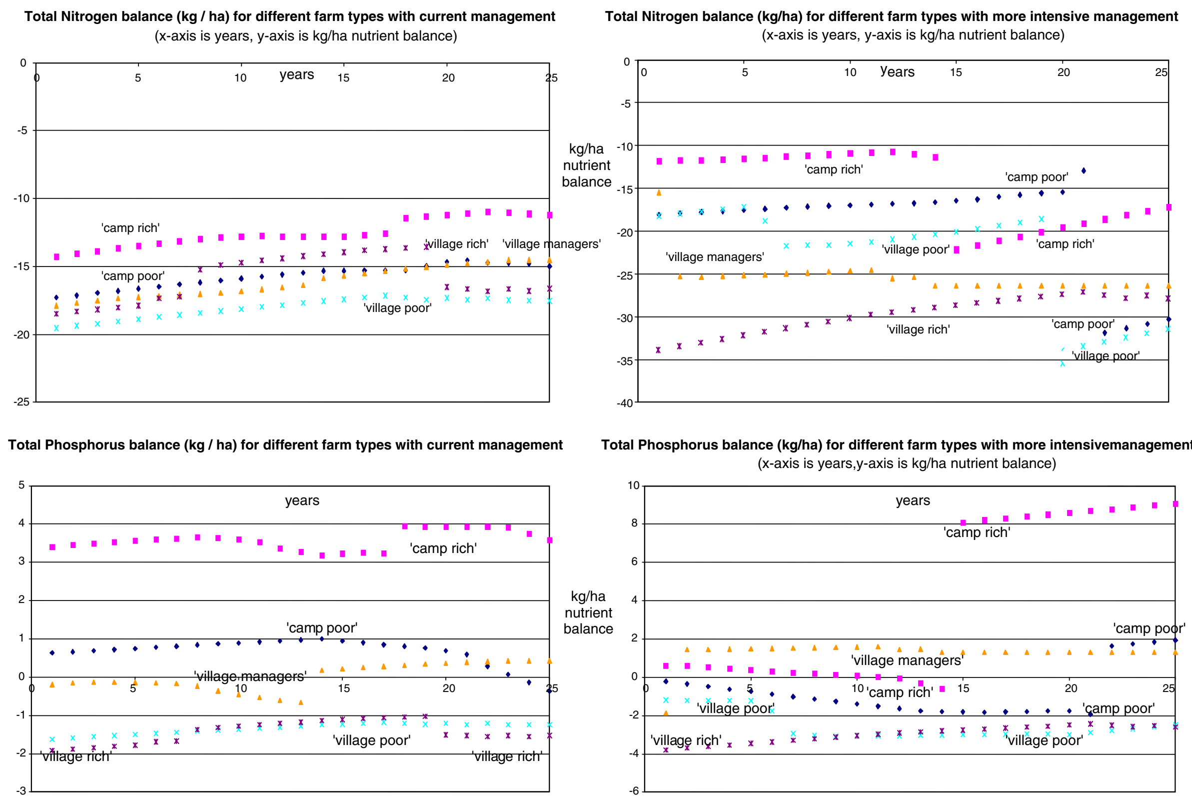

Fig. 1. Predicted changes in nutrient balances (kg/ha) for nitrogen and phosphorus under current and intensive management.

intensification due to declines in soil fertility. This affects their crop production, income and food security since they lack the financial and technical resources to acquire inorganic fertilizers or to buy food from the market. At the same time, on-farm meat and milk production of village farms is not expected to meet the future per capita consumption needs (La Rovere et al., 2005). Intensification and increases in livestock numbers at current growth rates will increase total meat production, though this comes with decreases in total milk production. This affects mainly the camp poor farms, as these are the only ones that do not have specialized livestock enterprises.

Impact of cropping intensity and management options on labor, income, migration

The static results of La Rovere et al. (2005) indicated that labor balances improve with intensification and population growth. More people will be available to meet the labor demand at peak times for cropping (weeding, harvest), and more-intensive farming will absorb more of the available work force. Yet this will only partially alleviate the labor scarcity of many farms as their productive capacity remains constrained by seasonal labor shortage. As labor balances in the early dry season deteriorate with intensification, this may become a critical period in farming. Income per capita grows with intensification, but real incomes per capita (discounted by the inflation rate) decline in the long run. Income from sales of livestock products contributes between 17 and 30% to total incomes of camp farmers, but only 5% for the livestock-poor village farmers. Off-farm incomes are a significant (10%) part of the total income of the poorer farms. The share of income from livestock declines with intensification, as does the income from off-farm labor, mainly for the livestock-endowed farms (Table 2). The share of income from crop production increases for all but the village rich farmers, whose structure of production is not affected by intensification. Only the village poor farmers remain in a situation of income insecurity (real income < 90 thousand CFA/year) under the conditions dominated by current forms of management.

The recursive projections reveal that under current forms of management, additional induced migration (Fig. 2) may affect the labor force of the camp poor farms as early as after 10 years and of the village poor farms after 16 years. This migration, however, is insufficient to alleviate, let alone reverse, current population pressure. Across-farm

Table 2
Changes (%) in income sources with intensification on five farm types

Farm types	Source of income		
	Livestock (%)	Off-farm (%)	Crops (%)
Camp poor	−6	−10	+16
Camp rich	−3	−14	+17
Village managers	−4	−8	+12
Village poor	−7	−3	+10
Village rich	−3	−1	+4

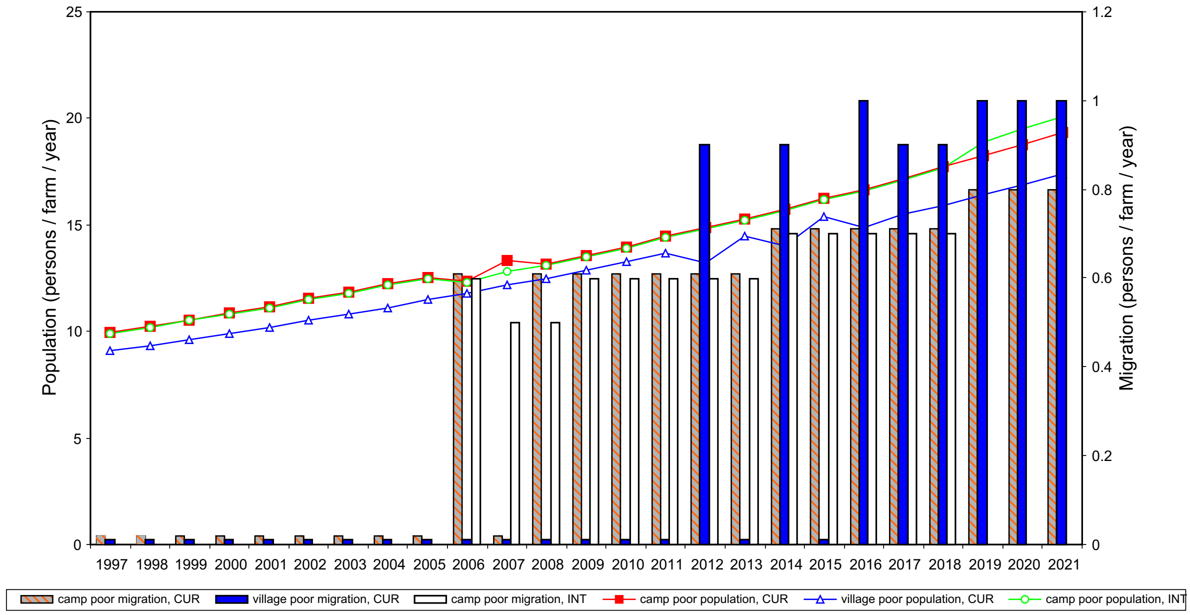

Fig. 2. Size and expected year of occurrence of induced annual migration and population for 2 farm types in south-western Niger. CUR: conditions dominated by current management; INT: conditions dominated by more intensive management.

labor exchanges may absorb part of the unemployed and improve the labor balance during the critical weeding periods. Labor would then shift to those farms that can pay for hiring it. Sensitivity analysis based on the opportunity costs of labor suggests that movements of laborers occur at times of seasonal labor shortages from the poorer towards the camp rich or better-off village farms, thus threatening the production potential of the former.

It has been indicated that explorative studies cannot be formally validated (Van Ittersum et al., 1998) due to discrepancies between assumptions and future conditions, yet average incomes at different intensification levels closely matched with survey-based incomes from the same area of the study. Also, the nutrient balances established in this study were similar to or less negative than those suggested by the papers reviewed in La Rovere et al. (2005). The trends, disaggregated per farm type, are more optimistic than those in Barbier (1999) and StruifBontkes and Van Keulen (2003). The study suggest that intensification is associated with a lower total capacity of livestock to compensate for nutrients exported in crops. This is in line with the observed decreasing rangeland to cropland ratios (Williams et al., 1995), while richer agro-pastoralists could sustain soil fertility over time.

The study suggests that intensification, in comparison to current management, would lead to improved livelihoods, though such livelihood benefits would be unevenly distributed:

- Food and nutritional security increase, because of increases in meat and milk production for the villagers, and in terms of additional cereals, for the poorer farms in general. Goat and cattle production, and millet and cowpea production, would contribute most to this.
- The general income level increases. However, the real incomes per capita decrease, undermining the already threatened economic situation, particularly of the poor villagers.
- In the long-term, labor constraints will be alleviated on most farms, as a result of an optimization of the seasonal distribution of labor; yet, this will not fully satisfy the labor demand of farms with labor constraints. Labor movement will increase from poorer to richer farmers and agro-pastoralists, and migration will increase, yet not to the point of buffering demographic increases. This may weaken the already low productive potential of the poorer farms, aggravating their economic insecurity, with the result that they may abandon farming and become specialized or urban migrant laborers. The poor farmers living in villages, two-fifths of all farmers, will increasingly face economic hardship.

Discussion of results

This study suggests, for the study area in south-western Niger, a cautious approach in predicting inevitable future losses in soil fertility associated with intensification and of the consequent frequently advocated need to compensate it with external fertilizer inputs.

Intensification was in fact associated with stable or even improving organic matter and P balances, but with deteriorating N status. N appears to be the main external input required to support intensification. To compensate for N losses, a combination of targeted and moderate use of inorganic fertilizers (Shapiro and Sanders, 1998) and of local coping strategies, i.e. improved legume varieties, leguminous tree fallows, herbaceous cover crops, higher share of cowpea in the intercrop ('integrated nutrient management', cf. with e.g. Place et al., 2003), can be effective and feasible in the short term (Breman and Van Reuler, 2002). Continued availability of phosphorus in the soil remains also critical to improve and maintain soil fertility (Kuyvenhoven et al., 1996), in general in West Africa. Declines in crop yields can to some extent be offset by systematic and effective recycling of organic manure (Gandah et al., 2003), by expanding cropland areas that benefit from livestock excretions, by increasing village animal numbers to increase the manured area (Schlecht et al., 2004) and by making more efficient use of manure by more frequent application of smaller doses. All of these options, though, are more likely to be accessible to the more endowed-farmers, rather than the poorer ones who may need them most.

It therefore seems that external (nutrient) inputs may not always be necessary, or the best or only way to achieve sustainable development in this study area in south-western Niger. Yet this scenario may not be valid indefinitely. The model shows that for south-western Niger the 'time bomb' (Batterbury and Warren, 2001) associated with declining soil fertility and with the inability of local systems to respond quickly enough to increasing population pressure (McIntire and Powell, 1995; Breman et al., 2001), could be set off by the second decade of the century by increasing cropping intensity triggered by population growth. At that point, resource limitations may be reached and reliance on external inputs would become the only option, so that fertilizer use – in addition to manure – is inevitable to improve yields (Tiffen and Mortimore, 1994; De Jager, 2005; De Ridder et al., 2004).

Conclusions and implications

Many studies have emphasized that agricultural development in the Sahel ultimately depends on external mineral nutrient inputs. Yet these studies either provide 'blanket solutions' or don't provide realistic strategies for the complexity of Sahelian systems. Recommendations based on the findings of aggregate nutrient deficits in West Africa may often be further weakened by the fact that policy conclusions on fertilizer needs are based on nutrient budgets that become increasingly negative as the spatial scale of the study increases from the farm to the sub-continent (Schlecht and Hiernaux, 2004), since nutrient flows, and communal management, are often not internalized in upscaling. In addition, conclusions with respect to regional assessment of P and N fertilizer effects, based on long-term multi-site experiments, are often lacking (Buerkert et al., 2002) or are based on relatively weak or location specific data. Although assumptions have been made in our study, the coefficients that were generated build upon a very strong dataset, and the outputs obtained were in large part validated, hence are likely to be within feasible limits.

Other key problems that hamper the implementation of recommendations to add external inputs involve prices, as prices of staples may collapse due to inelastic demand or supply change from climate or state intervention in lower rainfall years (Abdoulaye and Sanders, 2005); and the often concomitant unavailability or lack of land to allow fallow or grazing, capital to buy fertilizer, means to transport inputs, means for pest control, labor for crops, and the local unavailability of mineral fertilizer (Gandah et al., 2003). Hiernaux et al. (1997), Scoones and Toulmin (1998) and Smaling and Toulmin (2000) also warn that social, market and economic constraints may make intensification through the use of external nutrient inputs not locally attainable or realistic in the near future, unless fertilizers become accessible, affordable and their use profitable. Scientists and policy-makers should therefore exercise caution in extrapolating policy implications from results obtained from data limited to specific locations or social groups, as done at times for West Africa. Implementing policy recommendations that advocate an increased reliance on external nutrient inputs would first require removing the constraints that hamper the integration of animals and crops as an endogenous solution. Policies to improve fertilizer supply cannot be separated from demand-side incentives. To ensure that investing in intensification inputs is profitable and affordable, it is crucial to improve input access; reduce input cost to farmers by investing in infrastructure; enhance fertilizer availability in proper quantities, package, and timing; and increase farmers' capacity for fertilizer use (Abdoulaye and Sanders, 2005; Larson and Frisvold, 1996). This can be done by proper credit schemes, off-farm income, reduced financial risk; and coordination or privatization of fertilizer market systems (Reardon et al., 1997). Endogenous options based on the use of local available inputs should be explored in addition to a continued attention for the need for a more targeted use of external inputs. Realistic policy measures that include pricing, marketing and trade strategies, and increase accessibility of external inputs to all target groups are needed to ensure that external inputs can complement endogenous solutions in stimulating sustainable intensification of crop-livestock systems in the Sahel.

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