What if commonly managed resources are privatised?

Bio-economic models to explore resource use change in rural Niger

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Abstract

In the semi-arid systems of the Sahel, agricultural production centres on pastoralism and crop-livestock integration. Animals mobilize soil fertility through manure production, graze crop by-products, and transfer nutrients from pastures to cropped areas. Yet various interacting factors (climatic variability, poverty, institutional constraints) limit the capacity of agricultural production to keep pace with the mounting needs of rising human and animal populations. Major local trends associated with population growth and intensification are: increasing cropping intensities which, with the expansion of cropland at the expense of rangelands, and the resulting breakdown of the fallow system, lead to declining soil fertility and low crop yields; seasonal migration of labourers and traditional transhumance of herds; and reduced access to and availability of good quality open-access grazing resources. The latter could, in the future, cause the socio-economic and agro-ecological spheres of current farming systems to evolve towards an increased privatisation of common property grazing resources (CPR).

The study examines the potential implications of this evolution, by exploring the impact that the integrated management of livestock and crops in rural communities of southwestern Niger has upon the performance and livelihoods of differently endowed farms, and upon agro-ecosystem functions. Different scenarios compare three sub-sites that differ in terms of their farming pressure, and to simulate the different future outcomes that would occur when more intensive forms of management would prevail.

We use an innovative analytical approach based on explorative bio-economic non-linear optimisation models to compare selected farm type performance indicators to reveal key socio-economic and ecological trade-offs and simulate the *dynamic* effects of reaching critical natural resource use and social thresholds, recursively projected to 2020 futures.

It reveals that, if current agro-ecosystems evolve toward an increased privatisation of grazing resource use, soil fertility is likely to deteriorate on the lands managed by the semi-nomadic agro-pastoral groups and improve on those managed by the livestock-scarce villagers, though at the cost of declining farm incomes. The agro-pastoral groups are likely to resort increasingly to more distant pastures for feed, while the village-based, livestock-endowed farms to on-farm crop residues. Intensification, though associated with relative decreases in real incomes, will enhance food security, except for the poorer residing in villages. The study shows that soil fertility does not irreversibly deteriorate with intensification. Owning livestock can allow 'some' farms to achieve food security *and* maintain soil fertility by capturing and mobilising soil nutrients. Intensification will bring socio-economic gains but its benefits will be unevenly distributed. The poor village people above all will face hardship or be forced to migrate.

Keywords: Sahel, bio-economic model, privatisation, intensification, recursive scenarios

1. Introduction: the setting of the study

In rural Sahel population has been growing at a steady 3.4% (FAO, 2000), leading to intensification and reduction of fallows and common rangelands (Boserup, 1983). In Niger in particular, also the livestock population has increased, though at a lower rate than the human (Hiernaux et al., 1998b). Up to the 1960s the increasing food requirements associated with population growth were met by the expansion of cropland and increasing livestock numbers, but suitable land got exhausted as crops expanded in less fertile marginal areas. The reduction in rangeland and fallows made animal production increasingly constrained by forage availability, quality, and accessibility, which led to overgrazing of village lands and transhumance. In these environments, crop-livestock integration started becoming an alternative for maintaining soil fertility.

The interaction on-farm of pastoralism and mixed crop-livestock farming (Slingerland, 2000) provides, through the animals' excreta, means by which nutrients are transferred from grazing lands to croplands, thus allowing the spatial and temporal transfer of nutrients from rangelands and fields with low returns to higher return areas.

The access to grazing is regulated by sophisticated agreements between owners of the rights to crop the land, livestock managers, and traditional authorities. In these systems, referred to as 'shared-resource systems', access to *grazing resources* is de facto based on the number of livestock managed. Nutrients and organic matter from manure are shared between area grazed, including croplands when livestock graze crop residues, and farmland with the excretions of the animals' night resting (Hiernaux et al., 1998a). Systems based on *private use of grazing resources*, further referred to as 'privatised-resource systems', are spreading in the Sahel. The relative area cropped, the ratio of area cropped to total arable area, increases at the expense of fallows and rangelands. It differs from intensification, which involves higher use of productive inputs per area cropped in different combinations and degrees of intensity of labour, fertiliser, soil conservation measures, and crop residue management (Powell et al., 1996).

Research objectives

Having defined the major features and challenges in the area, two questions arise on the patterns and dynamics of the evolution of these farming and social systems:

(1) How would the present farming systems change under increased privatisation of use of common pool resources, particularly of grazing resources? and

(2) How will human and animal population increases impact on farmers' livelihoods, on the performance of differently endowed farms, and on the environment?

The large variability in Sahelian farming systems makes it impossible to give single answers to these questions, and entails a degree of complexity that requires a systems approach, which can be tackled by bio-economic modelling (Breman and De Wit, 1983).

2. Materials and methods

2.1 The farm household database

The study area is located in southwestern Niger, north of Niamey city. Three contiguous sites of the area – named after their largest villages: Banizoumbou, Tigo Tegui, and Kodey - share the same tropical semi-arid climate with 450 mm annual average rainfall — same geology, soils, and geomorphology. The sites differ in terms of the relative area cropped, of their settlement and land use history, and density of human and livestock populations (Hiernaux et al*.,* 1998b). The Djerma people, originating from upstream Niger, shifted progressively south to the study area region. Their settlement was relatively independent of available land resources and governed by access to surface water or wells, or by the possibility to dig new wells around which seasonal cropping communities could settle. The Fulani inherited from their pastoralist tradition the husbandry skills, the seasonal herd transhumance, and the livestock capital. They, however, have become increasingly more sedentary. They now live in 'camps', situated around the predominantly Djerma villages, on which they depend for water. These camps are scattered and far apart to avoid mixing of herds, and located close to livestock paths to allow animal access to the camp during the growing season. They are progressively shifting to cropping, although they have no rights over the land that they access through 'manure-for-grazing' contracts with village farmers (Slingerland, 2000). Most village farmers hold traditional rights over the land, but own fewer animals. Some larger households own substantial livestock capital, in addition to being into cropping.

The farm database, developed by scientists from the International Livestock Research Institute (ILRI) in collaboration with the National Research Institute of Agriculture in Niger (INRAN) and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), included data on composition and activities of households (Table 1), on farm assets, land rights and management, livestock owned and managed, and equipment, documented for 542 farms from the study sites (Powell et al., 1996, Hiernaux et al., 1998a, 1998b; Turner and Hiernaux, 2002). It also includes spatial information on land tenure, land use, crop yields, seasonal vegetation mass and composition, and herd grazing itineraries over the three sites covering a total area of about 500 km^2. Primary data and statistics derived from the database are included in the model, directly or in the form of technical coefficients (TCs) required to quantify agricultural activities and agro-ecological processes. This was operationalised through an external technical coefficient generator (TCG) that integrates different databases and models or their results, and enables quantification of cropping systems in a transparent and reproducible way.

2.2 The modelling approach

The future impact on farm performance and agro-ecosystem functions of the privatisation of the use of common resources and intensification of management was examined by an approach (La Rovere et al., 2004b) that integrates socio-economic and biophysical databases and tools. This is based on a modified bio-economic non-linear farm household level model (Sissoko, 1998; Kruseman, 2000) that quantifies and compares farm household performance and agro-ecological indicators by scenario analysis. Geo-referenced inputs generate spatially explicit outputs for GIS visualization, to relate livestock-mediated soil fertility to different soils and farms. The model addresses the farm household level with *ad-hoc* routines that aggregate specific resources (land, labour, forage) at the community level to account for limited community resources, and to avoid that these might be trespassed in the scenarios. To account for the open access of grazing resources and for herd mobility, an algorithm was developed to calculate livestock intake and excretions outside farm boundaries.

The questions of management intensification and / or resource privatisation were addressed through explorative scenarios to answer 'what-if'-questions on the system evolution from the relatively extensive land uses of site Banizoumbou to the more intensive ones of site Kodey. Privatisation involves a change from current conditions — with communally managed open access resources — to expected futures with increasingly privatised grazing resources. This may involve a progressive shift to:

- Restricted use of crop residues. This does not require changed land tenure systems, but private harvesting and stocking of residues.
- Restricted use of fallows. This requires an extension of existing inherited rights - that allow cropping the land and future harvest of crop residues – to a private use of land resources when converted to fallow.
- And, in the longer term, restricted use of non-arable rangelands.

  This will require the creation of new tenure rights to accommodate ranching.

Current and more intensive, locally feasible modes of production were defined to simulate the combined adoption of crop and livestock management options. They include alternative crop residue management, labour input, use of mineral fertilisers or manure (collected in corrals / paddocks, transported and applied manually to the field, or deposited on the fields by corralled animals), different lengths of fallows which influence the relative area cropped within farmlands, and soil conservation.

2.3 Scenarios modelled

The system is explored by projecting scenarios to a 25-year future to identify differences in farm performance and resource use at various levels of *relative area cropped* and *intensification*. The spatial variability in relative area cropped in the study area ranges from low (<25%) to high (>90%), which includes the relative area cropped at three sites of the area: Bani (40%), Tigo (50%), and Kodey (65%). The levels of cropping system intensification are defined in terms of combinations of inputs (manure, labour, fertilizer, draft power use) and fallow length (La Rovere et al, 2004b). The socio-economic and land use databases were used to characterize farm types. Based on the type of settlement and of endowment in cropland and managed animals (cropland access, herd size / composition, human and animal labour), five farm types were stratified (Table 1).

Table 1 Farm household typology and agro-economic information

Farm (Household) Type:		*Camp*		*Village*		
		Poor	Rich	Managers	Poor	Rich
Average family size	Persons	9.60	9.59	15.59	8.79	8.27
Labour availability	aleq[1]	5.84	5.43	8.38	4.94	4.53
Livestock: Total	TLU[2]	5.54	15.48	11.2	1.37	0.96
Average transhumant animals	TLU	2.5	7	1.2	0.14	0.10
Traction: Oxen, donkeys	(head)	2.49	3.53	2.25	0.58	0.47
Land availability	(ha)	8.71	12.66	25.24	9.06	21.38
Cropland per adult	ha/aceq[3]	1.3	2.3	2.5	1.6	4.3
Cropland per TLU	ha/TLU	1.57	0.81	2.13	6.61	22.27
δ-factor of grazing resource use proportionality[4]		*1.84*	*3.55*	*1.31*	*0.44*	*0.13*

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[1] Adult labour equivalent

[2] TLU is Tropical Livestock Unit, a hypothetical animal of 250 kg live weight. Used to bring different animal species under a common denominator

[3] Adult consumer equivalent

2.4 Model assumptions and definitions

In the model, fallow is considered to have two functions, a land use part of the crop rotation system managed within the farm, and a source of animal feed managed communally. The agronomic rationale of this derives from the need to replenish organic matter and nutrients during the fallow period, and the provision of grazing.

It is generally accepted (Penning de Vries and Djitèye 1991; Breman and De Wit, 1983) that in the Sahel, while crop growth is driven by soil moisture, productivity is limited by soil nitrogen and phosphorus, in part related to rainfall and organic matter content.

The pasture area accessible to farm animals was calculated (within the limits of available pastureland) by assuming that pasture area used was proportional to the number of livestock managed at specific times of the year. This proportionality is made operational through a farm type-specific δ coefficient (Table 1) calculated from data on land, livestock and pastures, aggregated over the total number of farms within a site. In calculating δ**,** total availability and use of crop residues is taken into account and allows considering the possibility of using common-pool feed resources or crop residues in proportion to the herd size (expressed in Tropical Livestock Units[5]) managed, and in relation to the number of TLUs managed by other farms. For instance, a δ of 1.84 for 'camp poor' farms means that they have access to 84% more land and feed than they own. This parameter is at the basis of scenarios that simulate privatisation; its presence refers to a situation with shared use of grazing resources, its absence to privatisation.

Total Digestible Organic Matter (DOM) annually required by a tropical livestock unit (TLU) was calculated at 1100 kg, based on an estimated maximum of 2300 kg Dry Matter [DM] intake, and a value for DM digestibility of 40 to 55% (Hengsdijk et al., 1996). If feed availability fell below this threshold, then quality feed available on-site for the livestock of a given farm was probably becoming scarce. This might trigger the herder's reactive decision to move the animals through transhumance to areas with higher feed availability. In terms of food security, annual (human) consumption requirements of grain were assumed to be: 200 kg/adult equivalent for nomads, 250

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[4] See text for explanation

[5] Customarily defined as a hypothetical animal of 250 kg live weight.

kg/adult equivalent for settled rural people (AP3A Project, 2001). For nutritional reasons, part of the food requirements is assumed to come from meat (18.25 kg) and milk (49 kg) (CIPEA/ILCA, 1994). Farm income, based on survey data, consists of net income from sales of crops, livestock, animal products, and off-farm labour. Annual minimum income estimated as sufficient for subsistence (90000 CFA p.c.) is a proxy for total monetary value of the nutritional requirements per adult equivalent at market prices, plus a premium to cover expenses to meet social obligations. Off-site emigration of labourers is estimated to involve about 10% of actives (~ 56.5 % of total population) ranging between 8% for pastoralists (‘camps’) and 12.5% for farmers (‘villagers’).

2.5 Key static equations

The model (Appendix 1 for explanation codes) maximizes an inter-temporal utility function of food and income security (Sissoko, 1998; Kruseman, 2000; La Rovere et al., 2004b) to compare the performance of different farm types at different levels of relative area cropped and intensification. Total income equals the value of crop and animal production sales and off-farm labour earnings minus the costs for the household.

1) $NETINC = \sum_{c} CROPINC_{c} + LIVINC + OFLINC - TCROCOST - LIVCOST - HLABCOST$

The cost of production includes the cost of crop and animal production and of hired labour. Corrected income equals net income plus the value of owned livestock.

2) $CORINC = NETINC + \sum_{t,r} pan_{t,r} * NANIMAL_{t,r} + pdonk*LABDONK + poxen*LABOXEN$

The equation below describes the labour balance for the farm household.

3) $LABBAL_{p} = TLABAVA_{p} - TLABREQ_{p}$

Total labour availability (family labour minus off-farm labour plus hired labour)

4) $TLABAVA_{p} < famlab_{p} - OFL_{p} + HIRLAB_{p}$

Total labour requirement (crop labour requirements plus herding labour requirements)

5) $TLABREQ_{p} > \sum_{c,s,a} labcrreq_{p,c,s,a} * LANDUSE_{c,s,a} + \sum_{t,r} labanreq_{p,t,r} * NANIMAL_{t,r}$

Aggregate nutrient balance (soil fertility status) is the difference between available and required nutrients for crop growth and organic matter mineralization.

6) $NUTBAL_{s,f} = NUTAVA_{s,f} + \sum_{ct,a} resnutreq_{ct,s,a,f} * LANDUSE_{ct,s,a}$

Available nutrients and organic matter from manure are proportional to farm animals and time spent in resting areas, along trails, around water sources, and grazing.

7) $NUTAVA_{s,f} = \delta*0.5*(\sum_{ct,a} fertava_{ct,s,a,f}*LANDUSE_{ct,s,a} + \sum_{c,a} falnutava_{'fa',s,a,f} *LANDUSE_{'fa',s,a})$
$+ 0.5 * (\sum_{ct,a} fertava_{ct,s,a,f} *LANDUSE_{'mi',s,a} + \sum_{c,a} falnutava_{'fa',s,a,f} *LANDUSE_{'fa',s,a})$

The organic matter excreted by animals is calculated from the fraction of indigestible organic matter (Schlecht et al., 2004). To account for the alternative management of excretions, the nutrients and organic matter from animal excretions were split:

- The excreta (faeces and urine) produced by animals during night corralling (50%) are managed on farm. These excretions are produced by the managed animals, proportionally to farm livestock density, as given by the farm-specific δ factor.
- The remaining half of the organic matter and nutrients is excreted by the animals along the grazing itineraries, irrespective of farmland boundaries (Turner and Hiernaux, 2002). The excretions left while grazing is proportional to grazing time and animal numbers (Schlecht et al., 2004). Only what is proportional to land managed will return to the farm.

The balance of digestible organic matter (DOM) is availability minus requirements.

8) $\text{DOMBAL}_q = \text{DOMAVA}_q - \Sigma_{m,r}\, \text{tdomreq}_{q,m,r} * \text{DOMREQ}_{m,r}$

The amount of DOM available for grazing by animals of the different farms comprises the fraction of the crop residues left in the field, fallow forages, and rangeland pastures.

9) $\text{DOMAVA}_q = \text{TOTRES}_q + \sum_{e,s} \text{pastyield}_{e,s,q} * \text{PASTAVA}_{e,s}$

Pasture availability depends on season, type, and quality of the forage. In the model, the non-harvested fraction of crop residues (mostly 80% of millet stalks) is referred to as [***α***], the harvested residues (about 20% of millet stalks, part of sorghum stalks, and all cowpea haulms) thus represent [1-**α**]. The time before cropping, when fields are still accessible to animals and when short transhumance may occur on southern pastures is [*Ts*], the wet season when cropping takes place, fields are inaccessible to animals, and part of the herd goes on long transhumance to Northern pastures is [T_L]. After harvest, animals can access again the residues of the recently harvested crops during the initial part of the dry season [T_R] when millet residues on the field can be used by local herds. The [1-**α**] fraction of harvested residues is assumed to be consumed on-farm by the farm animals during the whole year until they are finished, except during T_R, when the [***α***] fraction of mostly millet residues is grazed in the fields. This is considered to be an open-access resource, grazed proportionally [***δ***] to the size of passing herds.

10) $\text{TOTRES}_q = \alpha*\delta * \sum_{s,a}\text{cropresy}_{q,\text{'mi'},s,a}*\text{LANDUSE}_{\text{'mi'},s,a} + (1-\alpha)*\sum_{s,a}\text{cropresy}_{q,\text{'mi'},s,a}*$

$*\text{LANDUSE}_{\text{'mi'},s,a} + (1-\text{Tr})\sum_{s,a}\text{cropresy}_{q,\text{'so'},s,a}\, \text{LANDUSE}_{\text{'so'},s,a} + (1-\text{Tr})\sum_{s,a}\text{cropresy}_{q,\text{'ni'},s,a}\, \text{LANDUSE}_{\text{'ni'},s,a}$

The organic matter of [***α***] is returned to the soil (along grazing trails or in corrals), and of [1-**α**] is mobilized with the harvested crop residues. Grazing and decomposition of fallow and rangeland forage are modelled in a similar way. The DOM to feed the animals, assumed proportional to herd size, is a combination of available feed rations and energy intake levels specific for each animal species. This doesn't account for the animals that leave on transhumance [*translvy*] for the average time when they are away (T_S+T_L).

11) $\Sigma_m \text{DOMREQ}_{m,r} > \Sigma_t[\text{domreqan}_{'ca',r} * (\text{NANIMAL}_{'ca',r} + \text{LABOXEN} - (T_S+T_L) * \text{translvy}_{'ca'})]$
$+ \text{domreqan}_{'sh',r} * \text{NANIMAL}_{'sh',r} + \text{domreqan}_{'go',r} * \text{NANIMAL}_{'go',r}$

Total annual manure production is proportional to farm animals. A fraction of indigestible organic matter present in animal diets is excreted in faeces [*indigom*].

12) $\text{MANURE}_{'OM'} = \Sigma_{m,r} \text{indigom}_{m,r} * \text{DOMREQ}_{m,r}$

The balance of DOM during transhumance time (T_S+T_L) is total DOM available minus the DOM required, not including the DOM requirements of transhume animals.

13) $\text{DOMBATRAN} = \Sigma_{bq} \text{DOMAVTRA}_{bq} - (T_S+T_L) * \Sigma_{m,r} \text{tdomreq}_{q,m,r} * \text{DOMREQ}_{m,r}$

The access to pastures available year-round [$\text{PASTAVA}_{'y's}$] during the short transhumance time that precedes cropping [T_S] and to pastures of better quality [$\text{PASTAVA}_{'w's}$] during the wet season [T_L], is also proportional to livestock.

14) $\text{DOMAVTRA}_{bq} = \Sigma_{e,s} \text{pastyield}_{'w',s,bq} * \text{PASTAVA}_{'w',s} + Ts * \Sigma_{e,s} \text{pastyield}_{'y',s,bq} * \text{PASTAVA}_{'y',s}$
$+ \Sigma_{ct} \text{RESCRTRA}_{bq,ct}$

Crop residues [RESCRTRA_{bq}] of better quality available to feed the animals that remain on-site during transhumance consist of millet residues left in the field after the previous year's harvest and consumed before the cropping season when fields are still accessible [*Ts*], and what is left of the harvested residues.

15) $\Sigma_{ct}\text{RESCRTRA}_{bq,ct} = \alpha * Ts * \delta * \Sigma_{s,a} \text{cropresy}_{bq,'mi',s,a} * \text{LANDUSE}_{'mi',s,a} +$
$+ (1-\alpha) * T_L * \Sigma_{s,a} \text{cropresy}_{bq,'mi',s,a} * \text{LANDUSE}_{'mi',s,a} + T_L * \Sigma_{s,a} \text{cropresy}_{bq,'so',s,a} * \text{LANDUSE}_{'so',s,a} +$
$+ T_L * \Sigma_{s,a} \text{cropresy}_{bq,'ni',s,a} * \text{LANDUSE}_{'ni',s,a}$

2.6 Projecting the changes to the future: key recursive equations

A recursive approach (see also La Rovere at al., 2004a) models the temporal, additive, and non-linear interactions by projecting scenarios to the year 2020 under the hypothesis of continuing steady population growth leading to increased pressure on land and resources (Boserup, 1983). Various resources (nutrients, labour, feeds) are limited or seasonally not available or not accessible. Resources, assumed to cumulate on annual optimal stocks to become initial stocks for next years may, at given points in time, become scarce and their marginal values increase when approaching availability thresholds. At this point the effects of their scarcity may also cumulate, and feedback on the system. This section simulates the feedbacks on soil fertility (nutrient status on yields), feed availability (feed scarcity on farmers' decision to transhume), and income and livelihoods (food and economic insecurity on the decision to emigrate) indicators.

2.6.1 Changes in availability and quality of feeds, and re-active transhumance

The recursive approach assumes that in the long term yields are negatively related to soil and fertility losses (Smaling and Toulmin, 2000). Endogenously generated cumulative nutrient balances represent the threshold below which there is a nutrient deficit. Liebig's law of the minimum' is assumed to hold with reference to phosphorus. There is no assumed substitutability between nutrients, as they have distinct functions in the plant growth process. The interactions of macronutrients, their complex dynamics in the soil, and the multi-year character of particularly the phosphorus investment (Van der Pol, 1992), are in part captured by the TCG. TCG also provide the 'initial stock' of available nutrients. Sources of nutrients considered in the study are manure, non-grazed crop residues, fallows, and inorganic fertilizers. When nutrient balances become negative, an endogenous yield decline function [QCLOSTP] is activated that describes the effects of phosphorus deficits [effphosd] on yields.

16) $\text{QCLOSTP}_{c,s} = \text{effphosd}_{S} / 100 * \text{QC}_{c,s}$, if $\underline{\text{and}}$ when $\text{NUTBAL}_{s,\text{"P"}} < 0$

17) $\text{effphosd}_{S\ y+1} = -\ \text{bilany}_{S\text{"P"}\ y+1} / (\sum_{ct,a} \text{resnutreq}_{ct,s,a,\ \text{"P"}\ y+1} * \text{LANDUSE}_{ct,s,a\ \text{"P"}\ y+1})$,

This is the ratio of cumulative [bilany_{y+1}] nutrient stocks over nutrients required to reach target yields, where bilany_{y+1} is the sum of optimal [$\text{NUTBAL}_{s,f\ y+1}$] and cumulative [bilany_{y}] nutrient balances:

18) $\text{bilany}_{S\text{"P"}\ y+1} = \text{bilany}_{S\text{"P"}\ y} + \text{NUTBAL}_{s,\text{"P"}\ y+1}$

Attainable crop production [QC_{CS}] depends on attainable yield, management, soils, and land use. Annual crop production [QCy_{CS}] is attainable crop production corrected for the effect of phosphorus deficiency *if*, *when*, and *where* (farm, soil types) this occurs:

19) $\text{QCy}_{CS} = \text{QC}_{CS} - \text{QCLOSTP}_{CS}$

2.6.2 Changes in availability and quality of feeds, and re-active transhumance

The herders' *pro-active* decision to provide animals with better quality feeds is the main drive behind the decision to transhume. For each farm type, an average number of livestock (*translvy*) are annually away from the community lands and therefore do not use the local feeds. However, the decision to transhume is also *re-active* to potential scarcity (quantitative or qualitative) of feeds. Feed balances take into account both the seasonal quantity and quality of available feeds. Wet season feeds are of superior quality though they may be less available or accessible; early dry season feeds are of lower quality though they are more widely available. Crop residues are available and accessible only from end of harvest season until late February. The study simulates the herders' re-active decisions driven by the scarcity or poor quality of community feeds, which drives the search for more or better feeds. The difference between available and required Digestible Organic Matter (DOM) is the surplus DOM available per farm during the year (Equation 8). The surplus DOM available per TLU and farm type on the community lands during transhumance time [DOMTLU] is calculated as the total DOM available for the livestock remaining in the community [AVDOMTRA] over the TLUs staying in the community. DOMTLUTR is the annual DOM threshold needed to raise one TLU. A DOMTLU below this means that the feeds available within the community for the remaining animals are getting scarce; hence the herder may decide to transhume more animals. Aggregated DOM balances are modelled in such a way not to exceed the total feed availability within the community. Hence, and similarly to equation 11, but limited to the time, animals, and resources available during transhumance time:

20) DOMTLUTR = AVDOMTRA / (herdsize – translvy)

2.6.3 Seasonal changes in employment and migration

The decision to seasonally migrate is often driven by income and food unavailability that prevent farmers and their families from meeting sustenance requirements. Some labourers may be *induced* earlier to seek off-farm income and better living conditions by migrating outside the community boundaries. Labour exchanges among farms contribute to balancing the employment situation. The study identifies if and when major trends triggered by population growth impact on farm types and population. Seasonal migration [EMIG] is a known fraction [emigrate] of farm labour availability [Equation 3, TLABAVA_p]. Migration is *induced* when minimum per capita discounted income [INCAPYC] thresholds [targinc] and food consumption [CONCAPY] requirements [consreq] are not met, and when farms face seasonal labour surpluses ($\text{LABBAL}_p > 0$):

21) $EMIG_P = emigrate * TLABAVA_{p,}$ ***if*** *$INCAPYC < targinc$,*
AND ***if*** *$CONCAPY < consreq$,*
AND ***if*** $TLABAVA_p > 0$

Those who migrate are mostly the adult males. Total annual *induced* migration [EMIGT] feedbacks on farm household population [POP], food demand, and on other variables, while seasonal migration feedbacks on seasonal labour availability [$TLABAVA_p$]:

22) $POP - EMIGT = popg * famsize$

23) $TLABAVA_p - EMIG_P = popg * famlab_p$

3 Results and discussion

This section discusses the outcomes of the future likely evolution of local systems towards, intensification of management, privatisation of common grazing resources, and their combined effect on ecological and social indicators, and the validity of the outputs.

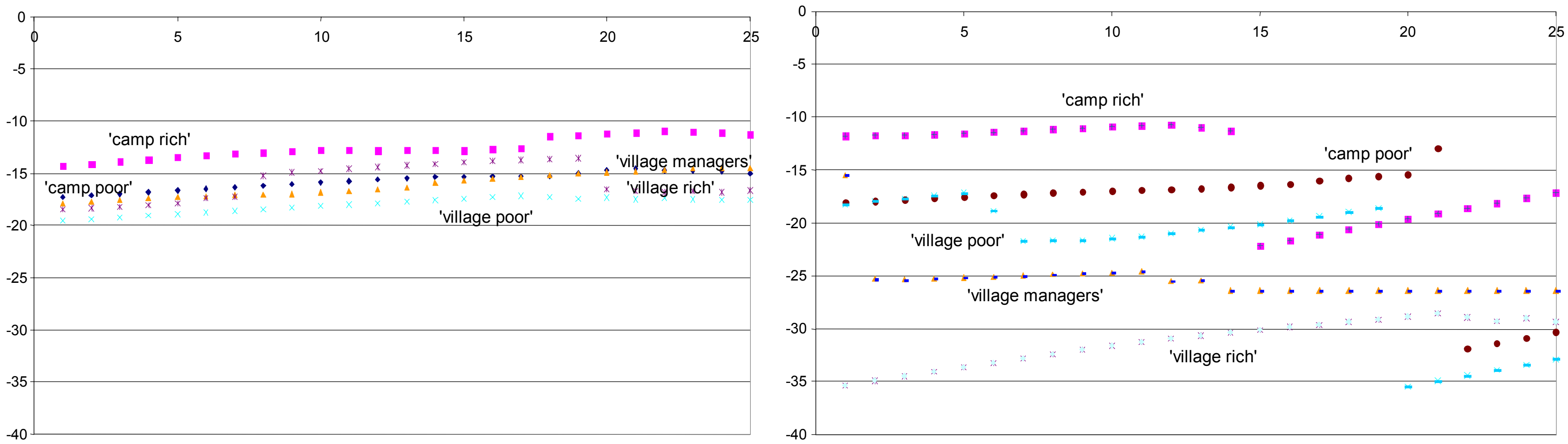
3.1 Soil fertility (see La Rovere et al., 2004b for further results and details).

The organic matter and nutrient status of lands managed by 'camp' farms is higher than that of the 'village' farms in current systems where resources are shared. With increasing intensification, N status generally declines, OM status varies, whereas P status is mostly unaffected or slightly improves. Intensification often prevents the organic matter balance of soils of the 'village poor' farms from turning negative, or even leads to an improved fertility status. Privatisation results in a decline in soil fertility status that affects the land managed by the 'camp' farms relatively stronger than that of the 'village' farms. The reason might be that, particularly under current management, the former profit less from the benefits associated with the sharing of open-access grazing resources and the latter benefit relatively more from the recycling of organic material produced on the land they manage. Privatisation, in fact, restricts crop-livestock interaction to within the farm; this entails loss of opportunities, due to mismatches in the balances between crop and livestock activities within the farm, unless there are institutional pathways for compensation (i.e. manuring or grazing contracts, or to sell crop residues). Under privatisation, managing livestock is rarely sufficient to prevent declining soil organic matter and nutrient contents. The benefits from manure are in fact limited by restrictions on access to grazing resources, particularly for 'camp rich' and 'village managers' farms with relatively large herds. The 'poor' farms residing in ‘villages’, instead, may be able to retain soil fertility on their land. In the long run (Figure 1) and with current forms of management, N status improves slightly but regularly, stabilizing (though at negative values) around year 2015. After that it worsens for the ‘village rich’ farms due to decreases in area cropped with millet and its cowpea intercrop. With intensification, several N balances become more unfavourable. These take the form of sudden changes in nutrient trends when farmers’ change their land use and management. After these sharp changes, N deficits appear compensated again, possibly by re-introduction of cowpea and other legumes. Future P balances of most farms remain fairly stable, regardless of management intensity. P balances of ‘camp’ and ‘village managers’ farms are in some cases positive under current forms of management. With intensification, the P balances of ‘village managers’ farms stay positive or improve, while those of ‘camp’ farms are at times negative. The ‘camp rich’, however, may introduce land management changes that favourably affect their P balances. Cumulative P deficits occur at times on ‘marginal silty’ soils for the livestock-endowed farms, and on all soils for village farms.

Figure 1: Prospective changes in nutrient (nitrogen, phosphorus) balances (kg/ha) with different management.

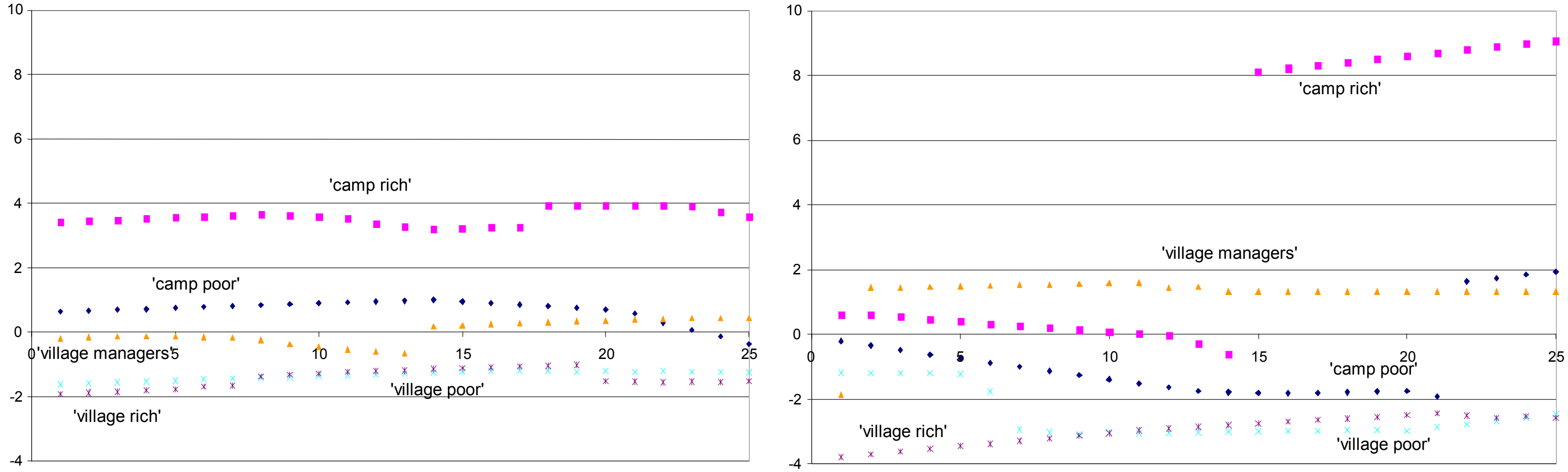
Total Balance of Nitrogen (kg / ha) for different farms with current management

Total Balance of Nitrogen (kg / ha) for different farms with intensification



Total Balance of Phosphorus (kg / ha) for different farms with current management

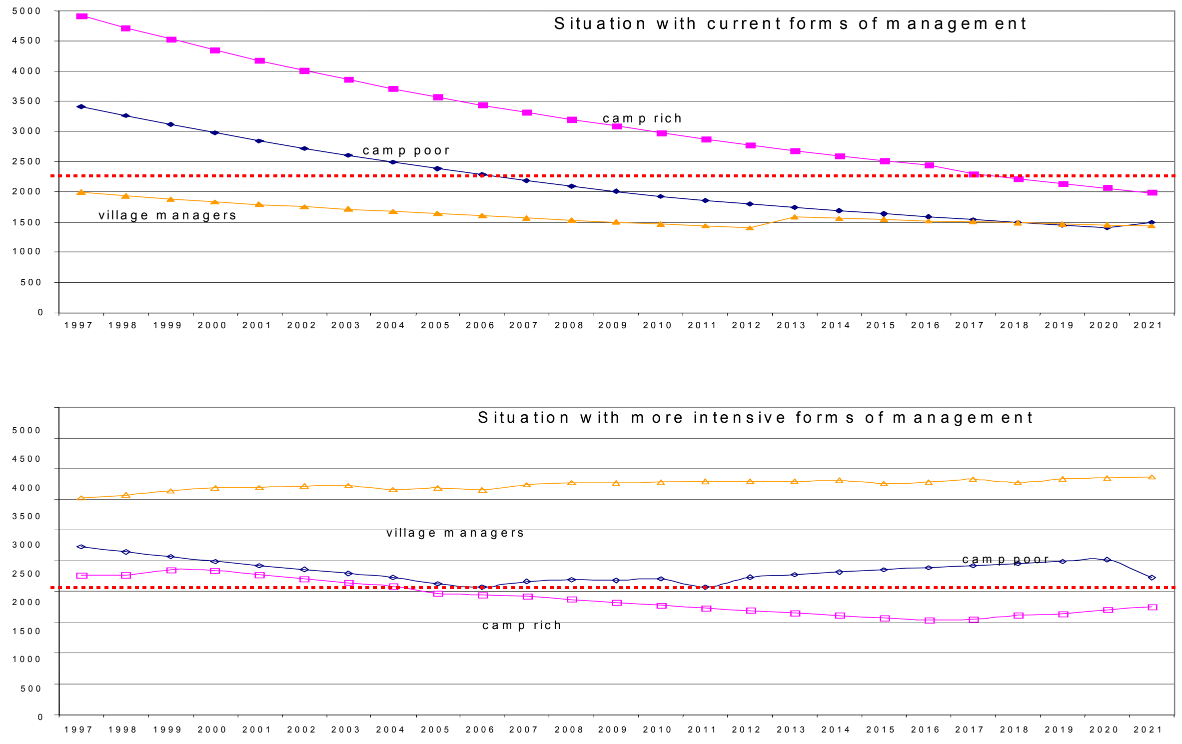
Total Balance of Phosphorus (kg / ha) for different farms with intensification



3.2 Feed availability

Under current management, *forage shortages* limit the livestock production of the 'village managers' farms (< 2300 kg Dry Matter (DM) / year). Intensification, leading to increased availability of crop residues and a higher share of legume crops in the rotation, results in higher feed availability and animal production capacity for all but the 'camp rich' farms, which experience a 10% decrease in annual available dry matter (La Rovere et al, 2004b) and will depend more on transhumance. With privatisation, feed availability differentially changes among farms; the 'village rich' rely more on crop residues, the 'camp' farms on pastures. In the long run (Figure 2) the feed status of the 'village managers' will likely lead to self-sufficiency due to more widely available crop residues. Feed shortages may start affecting the 'camp' farms and demand more frequent entrusting or transhumance of animals. Yet the system seems to be resilient as, after continuous decreases, feed availability recovers from around years 2010-2015 for the 'camp' farms (cfr. Mortimore and Adams, 2001; Batterbury and Warren, 2001).

Figure 2: Prospective changes in available DM (kg/TLU) for livestock-endowed farms



Dotted Line (~ 2200 kg DM) shows total feeds required per TLU and year to sustain herd growth.

3.3 Food production and consumption

Most farms are able to meet their annual cereal consumption requirements already with current management in the shared resource system, except for the ‘village poor’ (225 kg, versus 250 kg required for settled farmers), while the ‘camp poor’ are at the edge of food security (217 kg, versus 200 kg required for nomads). With increasing intensification, crop production can increase by 75-91%. Under privatisation the ‘camp’ farms show highest increases in crop production (+82%), the ‘village rich’ +59%, the ‘village managers’ +74%, while the ‘village poor’ can increase production by only 15%.

On-farm per capita meat and milk production of the ‘village poor’ and ‘village rich’ households (Table 2) never meets their consumption needs. Under privatisation meat production increases by 4-8%. Despite this, the consumption requirements of most ‘village’ households cannot be met. Under privatisation, relative milk production decreases by 6-19% particularly for farms having smaller herds. This seems to be linked to changing herd composition, to a specialization in favour of market-oriented meat production, and to the concentration of animal production at the larger livestock farms.

Table 2 Meat and milk production and predicted change as a result of privatisation

Current Management				
	Meat		Milk	
	(kg y^{-1})	*(kg $y^{-1}aceq^{-1}$)	(kg y^{-1})	*(kg $y^{-1}aceq^{-1}$)
camp poor	365.6	53.6	600.6	88.1
camp rich	1038.0	169.1	1531	249.3
village managers	687.3	70.1	930.6	95.0
village poor	74.7	13.0	106.1	18.4
village rich	57.4	10.9	73.8	14.0
Range of expected change with privatisation				
All households	+ 4 to + 8 %		- 6 to -19 %	

Legend: *Kg/year/adult consumer equivalent (aceq); ** No expected change.

The per capita long-term crop production of the ‘village poor’ farms is expected to decrease with intensification due to expected declines in soil fertility. This may severely affect the production, income, and food security of the ‘village poor’ that lack financial and technical resources to cope with the situation (e.g. to acquire inorganic fertilisers).

3.4 Incomes and labour

Agriculture, under current forms of management, is an uncertain activity for the ‘village poor’ farms as their income is always below the minimum levels required for subsistence (**Table 3**). This does not change when relative areas cropped expand. Under intensification, on the other hand, all farms achieve higher incomes p.c. than what they require for subsistence. Under privatisation, however, incomes of the livestock-scarce ‘village poor’ and ‘village rich’ farms decline. Incomes on the ‘village managers’ and livestock-endowed ‘camp’ farms decline if privatisation follows intensification.

Table 3 Changes in household incomes from shared resource systems to privatisation

Annual incomes p.c. (CFA) at different relative areas cropped, management intensification, and privatisation

Relative area cropped >>	25%	40%	50%	65%	90%	>90%	*Change with*
Farm Types Study sites:		**Bani**	**Tigo**	**Kodey**			*privatisation*
Current management							
'camp poor'	86437	100928	103984	108349	111754	112712	+ 3.5
'camp rich'	199462	233048	240173	250435	258554	255294	+ 6.9
'village managers'	109562	130456	134885	141229	146317	147584	+ 2.4
'village poor'	43942	52227	53985	56496	58504	58991	- 9.7
'village rich'	94375	110706	114153	119102	123061	124065	- 19.8
More intensive management							
'camp poor'	126847	140886	143858	148393	151885	153204	- 6.2
'camp rich'	255568	288427	295773	305951	314093	316634	- 1.6
'village managers'	179539	203930	208365	214703	219772	221065	- 2.6
'village poor'	89645	97945	99714	102225	104249	106450	- 14.0
'village rich'	214634	230965	234429	239378	243337	245581	- 20.6

Under current management, considerable labour shortages affect the production of all farms during the ‘mid wet’ season, and for the ‘village rich’ farms in particular, during the ‘late wet’ and, less markedly, the ‘early dry’ seasons (Table 4). Under intensification, labour shortages decline, particularly during the ‘mid wet’ season, while they increase during the rest of the year. This is associated with a more optimal seasonal allocation of labour and a more balanced labour distribution between crops and livestock within the farm. These changes are linked to a more conveniently scheduled out-migration of labourers that allows them to be present on their land during peak cropping times, and seek off-farming wage-labour in cities or abroad outside of the cropping season.

Table 4 Current seasonal labour balances, change with intensification, and privatisation

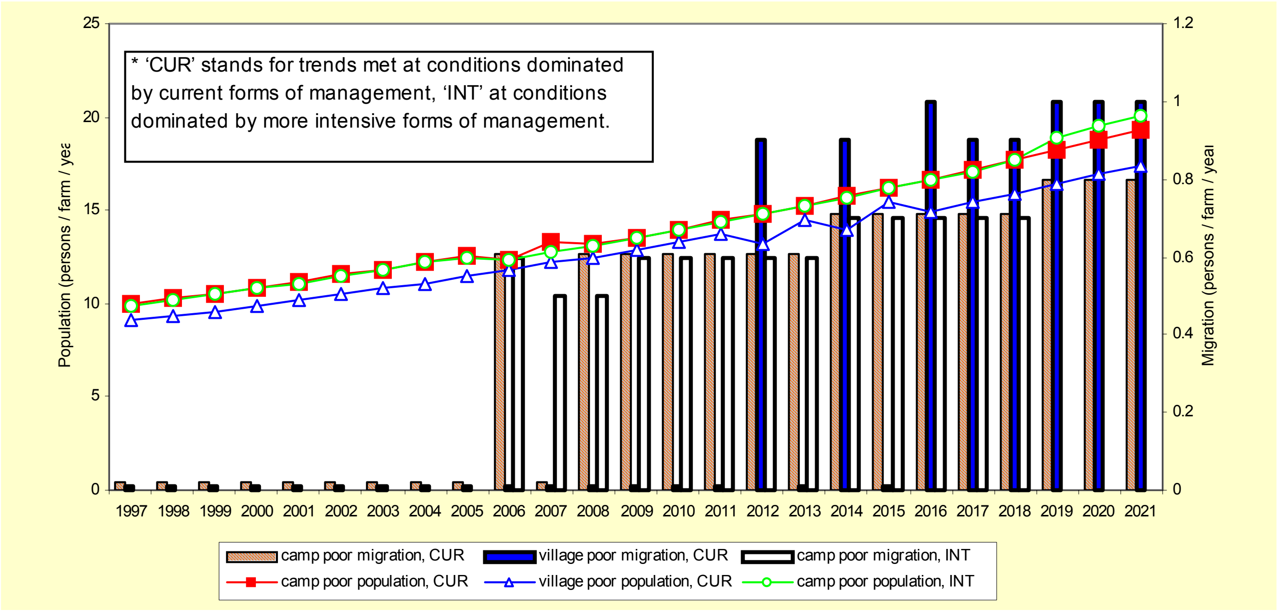
Seasons			Camp poor	Camp rich	Village managers	Village poor	Village rich
Dry	*Early*	(Cur)*	0.32	0.04	-0.01	0.22	-0.12
		(Int)	+0.06	+0.06	+0.05	+0.05	+0.04
		(Priv)	+0.01	-0.12	-0.14	-0.08	-0.07
	Mid-late	(Cur)*	0.57	0.29	0.25	0.49	0.15
		(Int)	-0.10	-0.12	-0.12	-0.11	-0.12
		(Priv)	-----	+0.02	+0.01	+0.02	+0.05
Wet	*Early*	(Cur)*	0.54	0.26	0.22	0.44	0.11
		(Int)	-0.12	-0.13	-0.11	-0.10	-0.12
		(Priv)	+0.02	+0.03	-0.01	+0.01	+0.03
	Mid	(Cur)*	-0.84	-1.11	-1.16	-0.93	-1.27
		(Int)	+0.60	+0.59	+0.59	+0.60	+0.60
		(Priv)	----	+0.01	-----	-0.16	-0.25
	Late	(Cur)*	0.20	-0.08	-0.13	0.10	-0.23
		(Int)	+0.14	+0.14	+0.15	+0.14	+0.14
		(Priv)	----	----	----	-0.04	-0.07

Legend: Seasonal labour *balance* *(person-days / year / ha) with (CUR) current management; (INT) *change* of balance after intensification, and (PRIV) *change* after privatisation of current shared resources.

Increases in labour availability particularly for the labour-scarce ‘village rich’ farms are not enough to avoid shortages during weeding and harvesting times. Seasonal labour deficits are exacerbated by privatisation in the ‘mid-late wet’ to ‘early dry’ seasons, above all for the ‘village poor’ and ‘village rich’ farms. The additional ‘induced’ **migration** (Figure 3) driven by food and economic insecurity could start affecting the ‘camp poor’ as early as year 2006, and the ‘village poor’ from year 2012. Across-farm labour flows may absorb part of the unemployed and improve the labour balance in the critical seasons. Labourers would then shift to those farms that can pay for it. Opportunity costs suggest that major viable labour transfers will occur from the ‘poorer’ to the ‘camp rich’ or ‘village’ better-off farms, further affecting the farming potential of the ‘poorer’ farms.

In the long term, labour constraints will be alleviated for the most affected farms, as a result of a greater scope for optimising the seasonal distribution of labour, however not to the point of fully satisfying their labour demand. Migration will increase in the medium term from the ‘poorer’ to the ‘richer’ farmers and agro-pastoralists, yet not to the point of counterbalancing current demographic trends. This may undermine the already low productive potentials of the poorer farms and hence aggravate their economic insecurity.

Figure 3: 'Induced' migration and population: size and likely year of occurrence.



3.5 Validating the modelling results

Our 25-year prospective soil nutrient trends generally match with those reported for comparable systems and scales in the Sahel (Savadogo, 2000; Van der Pol, 1992; Stoorvogel and Smaling, 1990), but are more optimistic than other studies (i.e. Barbier and Hazell, 2000; Struif Bontkes, 1999; Sissoko, 1998). Prospective explorative studies cannot however be *formally* validated (Van Ittersum *et al.*, 1998) due to inherent discrepancies between assumptions for the future and actual conditions (Kruseman, 2000). Outputs describing prospected changes at the study site have been compared to actual conditions at other locations in the Sahel that represent further levels of evolution of current systems. Income levels, in particular, match closely those from survey data for similar areas in Niger's Sahel. Prospective studies can generate outputs for GIS-based maps that can be compared with multi-annual field observations and maps, studies in similar areas that may represent likely future developments of the area, and model outputs simulating current conditions.

4. Conclusions

The study has revealed differential impacts of the anticipated evolution of farming systems in southwestern Niger towards adoption of more intensive forms of management and privatisation of commonly managed grazing resources.

In present systems, farm households that manage substantial numbers of livestock can take advantage of the use of communal grazing resources thanks to animal mobility, hence benefit from the integrated management of crops and livestock (Achard and Banoin, 2003). Their use of local resources is facilitated by the existing web of arrangements between local institutions and stakeholders from different ethnic and social groups. Severe income and food insecurity will affect mainly the 'village poor'.

Increasing intensification may impact differentially on soil fertility, and the related food and economic security of different farms. Most remarkable is probably that nitrogen balances are likely to deteriorate in most cases as a result of management intensification, suggesting that nitrogen may be the major external nutrient input that will be needed to sustain the process of agricultural intensification. This finding, that may have several policy and management implications, needs to be interpreted in the light of the complex interactions and dynamics of soil nutrients and of the long-term character of improvements in soil organic matter and nutrient contents. These characteristics, as well as ways to account for other nutrient flows linked to hydrological and atmospheric flows, and soil erosion, could not be fully taken into account in the model and are aspects of complex systems that need further research.

Another overarching outcome is that intensification will generally lead to increased agricultural production and improved food security and income conditions for the population in the area. However, that will not be sufficient to lift the currently most affected group – the 'village poor' – away from serious vulnerability threats to their livelihoods. These are the most represented in the area (about 40% of all households and population, La Rovere et al., 2004b) and still need to be the focus of development action to reduce malnutrition linked to animal protein and improve incomes.

Intensification, though leading to less labour shortages at critical times in the cropping cycle, does not fully remove the constraint of seasonal labour shortage, particularly not for the 'village rich' farms. Furthermore, expansion of the seasonal national and transnational out-migration towards cities and better salaries outside agriculture may exacerbate the already low on-farm productive capacity of the ‘poorer’ farm households. The study suggests that privatisation and particularly intensification will boost crop production. This is associated with expected increases in labour demand for cropping. Most households will however face increased difficulties in having sufficient labour available to meet this demand, especially during the peak labour periods in the cropping season. Labour shortages during the critical cropping periods could negatively impact on the productive capacity of particularly the ‘village poor’ farms, which are likely to face the highest future risk of economic and nutritional insecurity. Intensification will lead to higher *incomes*. The same will occur with privatisation, while maintaining current forms of management, limited to the livestock-endowed farms. If instead privatisation is associated with intensification, all farms are faced with lower incomes.

Finally, a few methodological remarks on what further research should focus:
- It is virtually impossible to capture nutrient flows linked to animal mobility by modelling only the farm level. If this were the case, scenarios would show that pastoral groups capture far less benefits than the poorly-livestock endowed ‘land-owners’. Our approach provides a way to explicitly model the effects of the shared use of common open-access resources, with access proportional to managed animals. It thus helps to avoid the risk of underestimating or misallocating the benefits of managing animals derived from grazing residues and releasing manure on arable land. Its success also depends on the availability of robust biophysical and land use data at the farm *and* community levels.
- Since in local social systems different (types of) households strongly interact, improvements in the approach should combine the farm and community scales (Kruseman, 2000) to allow for explicitly simulating farm dynamics (Struif Bontkes, 1999).
- The approach would certainly benefit of the simulation of stochastic events affecting resource variability and feed availability, primarily drought. Ways to account for shocks and changes in climate and resources could integrate external forecasts and forecasting methods from other disciplines to include time series and extrapolated future trends.

A host of studies has emphasized that agricultural development in the Sahel ultimately depends on external nutrient inputs (Breman, 1990; McIntire and Powell, 1993, Breman *et al.*, 2001). However, an equally impressive mass of literature (e.g. Smaling and Toulmin, 2000; Ayantunde, 1998; Scoones and Toulmin, 1998) warns that there are so many marketing and economic constraints, deep-rooted politically and culturally different realities, and agro-ecological and geographical differences, that reliance on external nutrient inputs under intensification may not be attainable nor be realistic in the near future unless fertilisers become accessible, affordable, and cost-effective. This should caution against extrapolating 'blanket' development solutions for the Sahel (Scoones and Toulmin, 1998). It is thus not always appropriate to advocate the 'external inputs' scenario as *the* solution, unless solid marketing, economic, and trade alternatives are suggested with respect to *where* these inputs may be coming from, *whether* they may reach all targets and groups, and *who* may be willing and able to pay for them, or perhaps take a better look at endogenous development options and coping strategies. The 'time bomb' (Batterbury and Warren, 2001) associated with declining soil fertility and the inability of local systems to respond quickly enough to increasing population pressure (Breman et al., 2001; McIntire and Powell, 1993), may not be triggered by intensification alone, but could be set off within the second decade of the century under increased farming pressure due to continuing population growth. At that point resource limits may be reached where reliance on external inputs could be the only option.

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Appendix 1 Nomenclature of selected variables and parameters

SETS

a	cropping activities	(different levels of relative cropped area)
c	crops /mi, so, ni, fa/	(millet, sorghum, cowpea, fallow)
ct(c)	crops without fallow /mi, so, ni/	(millet, sorghum, cowpea)
e	pasture types /w, y/	(type available in the wet season, and in the whole year)
f	SOM and nutrient types /SOM, N, P, K/	(soil organic matter, nitrogen, phosphorus, potassium)
t	animals /ca, sh, go/	(cattle, sheep, goat)
k	equipment types /ct, ox, do/	(carts, oxen, donkey)

m	animal forage rations	(different combinations)
p	labour periods /p1*p5/	‘early dry’, ‘mid-late dry’, ‘early wet’, ‘mid wet’, ‘late wet’
q	digestible organic matter (OM)	quality types
bq(q)	high quality digestible OM	quality types
r	feeding strategy /r1*r4/	(different energy intake levels)
s	soils /s1*s4/	(different soil types)

VARIABLES		**Unit**
NETINC	net income	CFA
CROPINC$_{c}$	crop income	CFA
LIVINC	livestock income	CFA
OFLINC	off-farm labour income	CFA
TCROCOST	total crop production costs	CFA
LIVCOST	livestock production costs	CFA
HLABCOST	hired labour costs	CFA
CORINC	corrected income	CFA
INCAPYC	target income threshold	CFA
CONCAPY	consumption threshold	kg
NANIMAL$_{t,r}$	number of animals	TLU
LABDONK	donkeys	TLU
LABOXEN	oxen	TLU
POP	Population	persons
EMIG$_{p}$	seasonal migration	persons
EMIGT	annual induced migration	persons
LABBAL$_{p}$	labour balance	aleq
TLABREQ$_{p}$	total labour requirement	aleq
TLABAVA$_{p}$	total labour availability	aleq
OFL$_{p}$	off-farm labour	aleq
HIRLAB$_{p}$	hired labour	aleq
LANDUSE$_{c,s,a}$	land use	ha
PASTAVA$_{e,s}$	pasture land availability	ha
TOTRES$_{q}$	total residue production	kg
RESCRTRA$_{bq,ct}$	residue production during transhumance time	kg
MANURE	manure left by animals	kg
NUTBAL$_{s,f}$	nutrient balance	kg/ha
NUTAVA $_{s,f}$	nutrient availability	kg/ha
DOMBAL$_{q}$	Digestible Organic Matter (DOM) balance	kg
DOMAVA$_{q}$	DOM availability	kg
DOMREQ$_{m,r}$	DOM requirements	kg
DOMBATRAN	DOM balance during transhumance time	kg
DOMAVTRA$_{bq}$	DOM availability during transhumance time	kg
DOMTLUTR	threshold of DOM per TLU during transhumance	kg

AVDOMTRA	DOM for the livestock remaining in the community	kg
$QC_{c,s}$	attainable crop production	kg/ha
$QCLOST_{c,s}$	yield loss due to nutrient deficit	kg/ha
$QCy_{c,s}$	annual crop production	kg/ha

PARAMETERS		**Value**	
α	non-harvested fraction of millet used	(0.8)	
δ	proportionality factor for shared grazing resource use	**Table 1**	
targinc	threshold (minimum) household annual income	ILRI survey data	CFA
consreq	annual cereal equivalent consumption requirements	ILRI survey data	kg
$pan_{t,r}$	price of animals (cattle, sheep, goats)	ILRI survey data	CFA
pdonk	price of one donkey	ILRI survey data	CFA
poxen	price of one ox	ILRI survey data	CFA
famsize	family size	**Table 1**	persons
popg	population growth rate	ILRI survey data	
emigrate	population emigration rate	ILRI survey data	
$famlab_{p}$	family labour availability	**Table 1**	aleq
$labcrreq_{p,c,s,a}$	human labour requirements for crop	ILRI survey data	aleq
$labanreq_{p,t,r}$	human labour requirement for animals	ILRI survey data	aleq
herdsize	initial herd size	ILRI survey data	TLU
$translvy_{t}$	transhumant TLU	Table 1	TLU

Fractions of the average year of key seasonal animal feeding and periods:			**Unit**
- Ts	last months before cropping (short transhumance to Southern pastures	($\frac{2}{12}$)	months
- T_L	long transhumance to Northern pastures	($\frac{4}{12}$)	months
- T_R	first months after harvest time (local animal mobility for residues)	($\frac{2}{12}$)	months

Selected datasets originating from the ecological and socio-economic surveys generated through the TCG system:

$fertava_{ct,s,a,f}$	external fertiliser available	Calculated with TCG
$resnutreq_{ct,s,a,f}$	crop nutrient requirement	Calculated with TCG
$falnutava_{'fa',s,a,f}$	fallow nutrients available	Calculated with TCG
$pastyield_{e,s,q}$	pasture yields	Calculated with TCG
$cropresy_{q,ct,s,a}$	crop residue yield	Calculated with TCG
$tdomreq_{q,m,r}$	digestible organic matter requirement (total)	Calculated with TCG
$indigOM_{m,r}$	indigestible OM	Calculated with TCG
$domreqan_{t,r}$	digestible OM requirement of animals	Calculated with TCG
$bilany_{s,'p',y}$	cumulative nutrient balance (spec. phosphorus)	Calculated endogenously
$effphosd_{s}$	cumulative nutrient deficit (spec. phosphorus)	Calculated endogenously