The Fakara: a semi-arid agro-ecosystem under stress

Report of research activities

First phase (July 2002-June 2004) of the DMP-GEF Program (GEF/2711-02-4516)
International Livestock Research Institute (ILRI)

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Table of contents

ILRI contribution to the Desert Margins Program

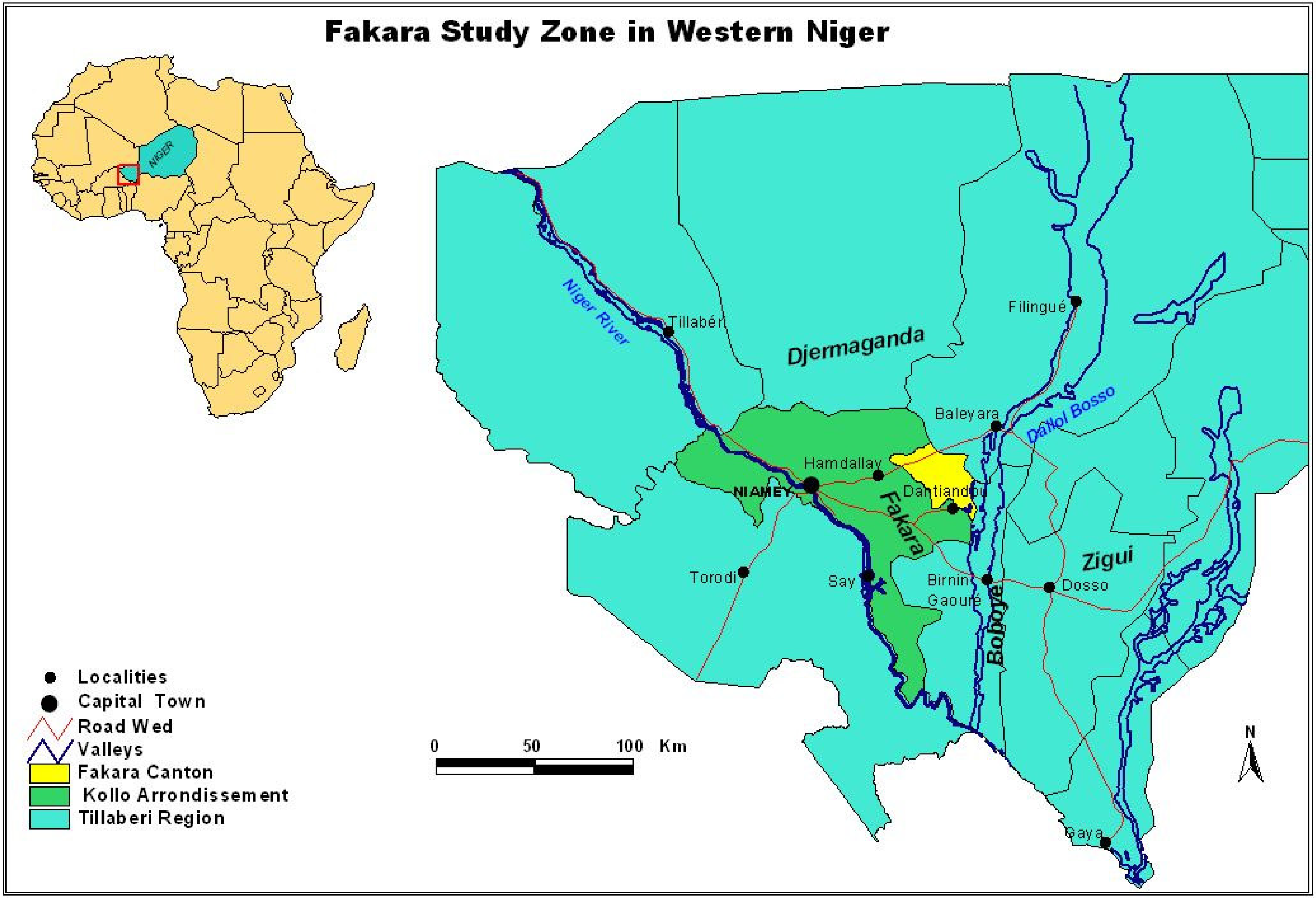
Besides the participation of the International Livestock Research Institute (ILRI) in the planning workshops and discussions that led to the writing up of the Desert Margins Program proposal, ILRI contribution to the first phase of the DMP-GEF program from July 2002 to June 2004 was centered on the development of methodologies to assess the natural resources of a Sahelian agro-ecosystem under stress, diagnosis of the status and trends of the productivity and the bio-diversity of the agro-ecosystem and performing preliminary tests of alternative management (DMP,2002). These activities are taking place in Fakara, a natural region, in an administrative district (canton) of western Niger, taking stock of the wealth of knowledge on the functioning of this semi-arid agro-ecosystem that resulted from a series of extensive studies carried out in this site from the 80's onward. These studies were devoted to the soils, climate, hydrology, vegetation components, fauna, crops, livestock and farming systems of a small natural region of western Niger. This research background is summarized in the following introductory paragraphs. Then, the document reports more specifically on the research by International Livestock Research Institute in collaboration with the National Institute of Agriculture Research (INRAN), the International Crop Institutes for Semi-Arid Tropics (ICRISAT), and also with the regional Center AGRHYMET and ' Projet Intrants', a rural development project developed by FAO and the Ministry of Agriculture Development of the Republic of Niger.

The Fakara study site

Fakara is a small natural region of Western Niger covering about 6000 km^2 between the confluent valleys of the Niger River to the West and the fossil valley of the Dallol Bosso to the East (Fig 1). The road Niamey-Baleyara follows approximately the contact between the Zarmaganda to the North and the Fakara to the south. Fakara is part of the Zarmatarey (together with the Boboye and Zigui located further East), the country of the southern expansion of the Jerma speaking people coming from the Zarmaganda, the historical cradle of the Jerma people. Though a Jerma region, Fakara also harbors a strong minority of Fulani people who dominate in neighboring regions to the West (Torodi, Ouro Gueladio), South (Say) and East (Boboye) (Beauvilain,1977). There are also small minorities of Hausa (Maouri) and Kel Tamachek people established in the Fakara. The Fakara extends over all of two administrative districts: Fakara and Kouré cantons, and part of Hamdallaye, Kollo and Birni Ngaouré cantons. The cantons of Fakara, Kouré and Hamdallaye are all part of the arrondissement of Kollo, itself included within the Tillabery administrative region of Niger (Fig. 1). The study site covers 500 km2 (included within latitude North 13^o 20' - 13^o 35'; longitude East 2^o 35' -2^o 52') all falling within the Fakara canton which administrative head is the small town of Dantiandou (lat N 13^o 24' 45", long E 2^o45' 23") located at 75 km to the east of the Niger state capital town, Niamey (Fig 1.). The study area encompasses 10 villages but also extend over the lands of surrounding villages. In 1998, about 6000 individuals are living in the study area all included in the canton of Fakara.

Front page photo: young transhumant shepherd on a livestock path in Kodey (Fakara)on his way to northern Sahel with his flock (photo P. Hiernaux)

Figure 1. Study site location in Africa and in Niger, within the region of Tillabéri, the arrondissement of Kollo: the canton of Fakara.



1. **Background**

1.1. The climate of Fakara is a typical inland semi-arid tropical climate with an average annual rainfall of 560 mm (1905-1989) and of 495 mm only from 1968 to 1989 (Lebel et al. 1997). Fakara is part of central Sahel bio-climatic zone (Fig 2). Rains fall in summer when days are long, ambient temperatures are elevated, and potential evapo-transpiration is high. Rainfall distribution is strictly monomodal, centred in August, with rainy seasons lasting 4 to 5 months. The rainfall distribution in the Sahel is often described as 'erratic'. Actually, the seasonal pattern of this monsoonal system is very regular, but the spatial and temporal distribution of rains during the rainy season is highly irregular and unpredictable. Annual rainfall at a given site varies from year to year with a coefficient of variation between 25 and 30% (Le Barbé and Lebel 1997). Most of the rains fall during the passage of squall lines or convective storms of high intensity. The high prevalence of intense rainfall events contributes to higher rates of soil crusting and runoff than would be expected from the sandy soils and limited relief that are typical of the Sahel (Casenave and Valentin 1989). The long dry season is also characterised by extremely low air humidity (daily minima < 5%) for 2 to 3 months, along with high temperature and aerosol density.

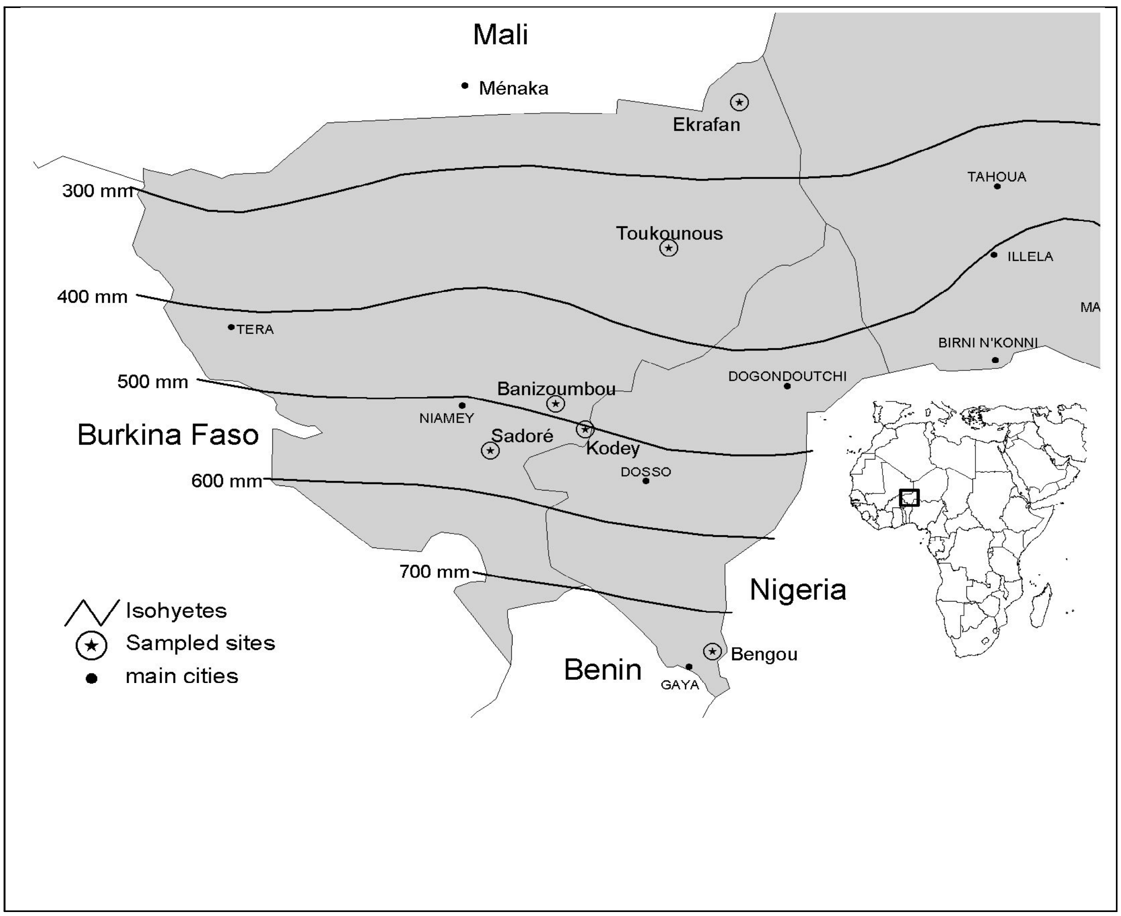


Figure 2. Location of the Fakara (Villages of Banizoumbou and Kodey) in the climate gradient of Western Niger.

1.2. Fakara is located within the sedimentary basin of the Iullemmeden (Greigert, 1966) that extends over 600 000 km^2 in western Niger and Eastern Mali (Fig 1). It lays on the south western edge of the basin, on a 150-200 meters thick horizontal sandstone deposits of the 'continental terminal' series of the 'moyen Niger' dated from mid Eocene to late Pliocene (Favreau, 2000). This geology explains the sandiness of the derived soils and their poor chemical fertility. Topography, geomorphology and soils are inherited from a long history of climate fluctuation during the quaternary: from hyper-arid to sub-humid. The landscape topography is dominated by the horizontal surface of the low sandstone plateau (actually the floor of the sedimentary basin), capped and protected from further erosion by a 5-20 m thick iron-pan ('cuirasse latéritique'). This iron-pan formed in the B-horizon of a deep ferric soil that developed in the late Pliocene under sub-humid tropical climate. This low plateau was dissected by the River Niger to the West and by the Dallol Bosso, a fossil affluent of the River Niger , to the East and by their tributaries. The Dallol Bosso used to drain waters from a large watershed centred on the Azawak basin extending to the Adrar of Ifoghas, Ahaggar and Aïr mountains. The Dallol Bosso carved in the continental terminal sandstones a 12-18 km wide valley bordered by cliffs (Beauvillain, 1977). This valley oriented North-South limits the Fakara to the east. As in all the Sahel, arid and sub- humid climates alternated during the quaternary shaping landscapes and soils. Wind erosion during the arid periods of the quaternary triggered the selective export of clays and loams deposited as loess further south as in the Kano area in northern Nigeria (Mortimore, 1989) and the deposition of sand on the slopes and in the valley, sometimes extending over the low plateaus. Sand deposits and dunes established during the more arid periods were then reshaped by water erosion and covered by savannas during the more humid periods of the quaternary. In spite of low altitude and quite homogeneous geological background, alternating arid and sub-humid climates during the quaternary resulted in a large diversity of edaphic situations, organised along the slopes in loose hierarchy (Fig 3). The chemical properties of the top soils, texture, acidity, organic and nutrient content depends on the age of the deposit, and the number, duration and extent of the dry and wet periods that occurred since they were put in place (Gavaud and Boulet, 1967). Soils differ across landscape but all tend to have low organic matter content and weak structure (Trop Soils, 1991;West et al. 1984). Cation exchange capacity, varying in relation to clay content, often very low, is usually unsaturated. Top-soils are acidic and poor in soluble nitrogen and phosphorus. Extensive research has confirmed that soil nutrient deficiency limits rangeland and crop productivity in the Sahel (Penning de Vries and Djitèye, 1982). Considering the water to nitrogen balance, Breman and de Ridder (1991) postulated that range production would become N-limited above 250 mm yr^{-1} of available soil moisture per year and established relationships to predict primary production from infiltrated rainfall and N availability, along with estimated N losses through grazing, volatilisation and leaching. In other Sahelian sites, less mobile P was recognised as the first limiting factor of primary production (Buerkert).

1.3. In accordance with the seasonal pattern of rain distribution in the monsoon system surface, water resulting from run-off is available in more or less lasting pools either on the poorly permeable plateau, in small depression at mid-slope or in the lowest parts of the fossil river beds (Fig 4). The overall system is endoreic. The water collected in these pools, often over very small watersheds, evaporates, a very small fraction is consumed by livestock, while a variable fraction infiltrates feeding the water table (Desconnet, 1994). In Fakara, this water table forms a sometimes piezometric depression centred on the valley of Dantiandou along which the water table is artesian. Recent studies based on piezometric monitoring and isotopic analyses, have demonstrated that the elevation of the water table has risen since the 50's due to higher infiltration, most probably caused by the changes in land use (Favreau, 2000). And this progressive rise of the water table occurred in spite of the decrease in rainfall that occurred since the late 60's and the increased water used by increasing population (human and livestock consumption, garden irrigation).

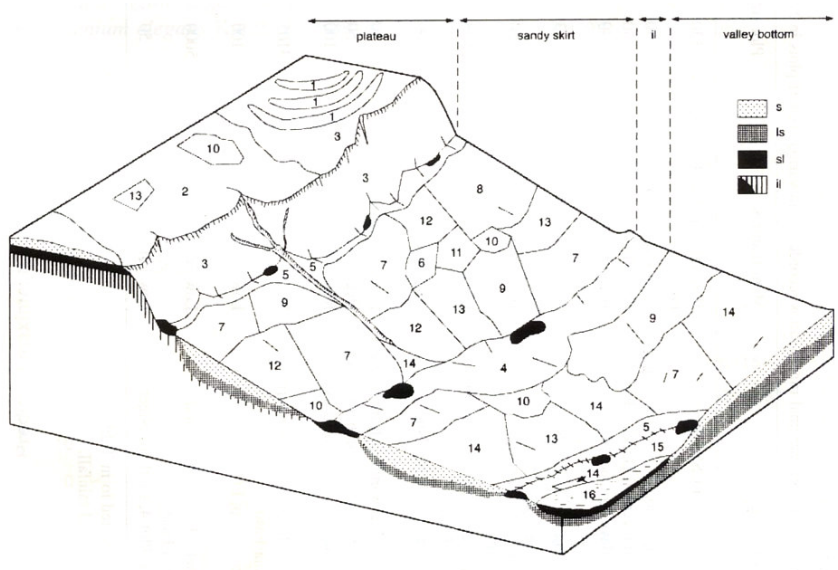
1.4. From sub-humid savannas to desert during the quaternary, the Fakara vegetation evolved during the twentieth century from a sahelian savanna to largely eroded park cropland. Main vegetation types are in accordance with soil-geomorphology situations and thus with the pattern of water and nutrient redistribution in the landscape. Vegetation is composed of two main components: the herbaceous layer dominated by long cycle annual grasses, and a scattered population of small trees and shrubs. Unlike other arid ecosystems, perennial grasses and under-shrubs are not common. The severity and long duration of the dry season inhibits perennials and succulents, while the seasonal regularity of the rains favours annuals with seeds that germinate actively with the first rains (Hiernaux, 2000). And among them, long cycle annuals are best adapted to the slow release of nutrients on these poor fertility soils. Moreover, the seed stock is transient, with only a few species producing seeds that remain viable over several rainy seasons (Carrière, 1989). Inter-annual fluctuations in herbage production and species composition are explained by the variable pattern of rain distribution during the wet season from year to year and site to site. Woody plants have variable leaf size and a diverse phenology, ranging from ephemerals to evergreens (Hiernaux and Gérard, 1999). They compete with herbs for water and nutrients in the top metre of the soil profile where most of their root system is developed. However, a few taproots assure their access to percolated water and shallow water tables (Breman and Kessler, 1995). This competition creates an equilibrium between herbaceous and woody plants, which, unlike other arid ecosystems does not lead to bush encroachment. Only in the 'brousse tigrées' (tiger brush), a patterned thicket common on very gently sloping hard pans in the Sahel with dense linear thickets alternating with bare soil stretches acting as natural water harvesting systems (Ambouta, 1997; Ichaou 2000), has woody plants won the competition (Hiernaux and Gerard, 1999). 'Brousse tigrée' is just an extreme case of vegetation patchiness in relation to the redistribution of water and nutrients, characteristic of the Sahelian woody plant population and at another scale of the herbaceous layer (Hiernaux, 1998). Vegetation diversity expresses thus in the patchy pattern related to the functional adaptation to spatial and temporal irregularity of, first, water and nutrient distribution, second, patchy and seasonal herbivory, and third, bush fires.

1.5. In contrast to other arid and semi-arid areas of Africa (e.g. Namib, Karoo), there are very few endemic species in the Sahel probably because of the amplitude of fluctuations in environment conditions in present time and during the whole quaternary, and the relative homogeneity of the soil background. Some species are locally rare, either because they are close to the limits of their distribution area or because of the small extent of their specific habitat like for wetlands or rocky outcrops. The transient nature of the seed stock causes the sharp changes in herbaceous vegetation composition often witnessed in monitoring studies (Cissé 1986; Boudet 1981, Carrière 1989, Grouzis, 1988). In spite of the wide amplitude of the inter-annual changes in production and species composition, natural vegetation is remarkably resilient to droughts, as demonstrated by the spectacular spontaneous 'regenerations' of northern Sahel rangelands following the drought crises in 1973-74 and 1983-84 in the Gourma region in Eastern Mali (Hiernaux 1995, de Leeuw,1993). The monitoring of woody plant populations in Sahelian rangelands indicates active dynamics, although at a more extended time scale than for the herbaceous community, including drought-induced mass mortality of populations at some time lag after droughts, and occasional waves of regeneration (Couteron and Kokou, 1997).

1.6. The agricultural system. Because of the difficult access to water and relative poor soil fertility, and also because of political insecurity, the Fakara has had a long history of sparse and low population density (Barth, 1854; Beauvilain 1977). It is only in the 20th century and especially since 1950's that population density increased steadily, following colonial 'peace', progress in well and later borehole drilling, improved health care and to some external inputs in relation to the proximity of Niamey the capital town of Niger. The agricultural system is characterised by the cohabitation of two agrarian cultures, the Jerma crop-farmer culture, and the Fulani pastoralist culture. There are in addition, small minorities of Jerma speaking Hausas, the Maouri (village of Maourey Zeno), and a few Kel Tamascheck Bellas (Camps in Boundou, and Tigo Zeno). For a century, both agrarian cultures have co-evolved towards sedentary crop-livestock systems (Bonfiglioli, 1990). The present farming system is largely subsistence oriented, based on millet staple (mainly millet and some sorghum) associated with a range of secondary crops, either dual-purpose legumes (cowpea, bambara nut, ground nut) or cash crops (sesame, sorrel). Indeed, the need for cash and development of the market of Dantiandou favoured the development of women garden productions. Depending on soil texture, tillage ranges from very extensive no-till practices on sandy soils to ridging or ploughing in the minority of finer textured soils. Because of no-till, the bottleneck of cereal cropping is often the time-labour required for weeding, the efficiency of which is as low as 0.15 ha per adult per day for manual weeding in western Niger. Low inputs and the inherent poor soil fertility generally limits yields and explains the periodic fallowing traditionally practiced to restore soil fertility (Achard and Banoin, 2003). In western Niger, average land cropped is less than 5 ha per household and less than 1 ha per adult equivalent in the densely populated Dallol Bosso (Beauvilain, 1977), while in less densely populated villages of Fakara, lying immediately to the west, these values increase to 13.2 ha per household and 2.3 ha per adult equivalent (Table 1). Such an average conceals significant variation among members of the same community. For example, the Jerma's historical claim to land in Fakara is reflected in their greater access to cropland compared to the Fulanis who are only recently involved in cropping activities. Within communities, the land cultivated per household varies significantly due to differences in effective access to land and labor, which reflects not only household size but also the wealth status of the family. Moreover, land access rights are generally restricted to adult men in spite of the large involvement of women in crop management. Cropping activities are associated with raising animals such as zebu cattle, sheep and goats as well as poultry, donkeys, and a few horses or camels. Following population increase, land cropped expanded rapidly since the 50's without much intensification of the production system. Internal inputs such as livestock manure and crop residues are in part recycled and concentrated on a fraction of the cropland continuously and more intensively cropped. Livestock ownership is most often individual and does not exclude women nor children. Hence, livestock is the major form of wealth storage in this area. The differences in livestock holdings are even greater than those in area of land cropped both within and across communities in the region (Williams, 1994). Over the past 25 years, livestock ownership has shifted partially to richer farmers, merchants, and civil servants (Moorehead, 1991). While these groups continue to rely on livestock specialists to manage their livestock (increasingly through wage contracts), poorer agricultural households are tending to manage their livestock themselves; former livestock entrustment contracts with livestock specialists have eroded following the decline of the historic patterns of pastoralists' movements (Benoit 1979). To a greater degree than the classical herd and family movements of the nomads (Bonfiglioli 1988, Schareika et al. 2001), pastoral movements in the Sahel were and remain dominated by the South-North fluctuations of the herds guided by individual herders or shepherds. Herds move towards arid rangelands at the onset of the wet season, returning progressively to semi-arid or sub-humid zones or to riverside areas where they spend the rest of the dry season, sometimes following another round of transhumance (Benoit 1979, Schlecht et al. 2001). During both seasons these movements aim at providing the best quality feed to the herds. The movements are controlled by water availability (Thébaud, 1999) but they are increasingly constrained by the reduction and fragmentation of grazing land areas in semi-arid zones and in flood plains (Moorehead 1991, Turner 1995).

1.7. Rapid urbanisation. The Fakara is located at 60-100 km to the east of Niamey, the capital of Niger. Niamey has grown very fast since 1950…The relative proximity explains the development of the market of Dantiandou, main market in the Fakara, located at the center of a triangle Niamey-Baleyara-Birni Gaouré, and related to the two tarred road Niamey-Filingué via Baleyara, and NiameyGaya via Birni Ngaouré. Thus, Fakara is rather well connected to the market for inputs and outputs through the Dantiandou market and secondarily through that of Jedda, Balleyara, Hamdallaye, Kouré and Birni Gaouré. However, the proximity of Niamey has not helped much the canton to benefit from service infrastructures, only half of the villages have primary school and literacy is very low. Only Dantiandou has a clinic.

1.8. Traditional institutions largely determine land tenure and land use system with primary usufruct rights on cropping lands held by descendents of village founders, and secondary usufruct rights acquired by negotiation with the beneficiaries of the primary rights. Ownership of livestock is individual, however dowries, gifts and lending systems such as 'talfi' and 'habanaï' are major institutions in the sharing of livestock wealth (Bonfigliolin 1988). Islam, a shared religion by all groups, supports cultural values of mutual aid and institutions such as common access to natural resources, especially pastoral ones. In spite of these shared social values the society is relatively individualistic when it comes to management decision. And in spite of political support, it was only recently that formal farmers' organisation (only among men and women from the Jerma community) emerged in relation to access to credit facility (MUTEC) at Dantiandou.



(Source D'herbès and Valentin, 1997)

Fig. 3 Three dimensions graph of main topographic and geomorphic features of Fakara.

2. Working hypotheses and rationale

Conservation and management of the biodiversity of the Sahelian agro-ecosystem is the way forward to combat desertification. It targets enhancing the resilience of the agro-ecosystem to increasing stresses and disturbances, and it also aims at providing options to farmers to improve their livelihood and escape poverty, which is a major cause of ecosystem degradation.

The Sahel, a semi-arid ecosystem, has evolved as an agro-ecosystem for at least the last six thousand years (Beauvilain, 2003). The Sahel is the cradle of major cereal crops such as Millet (Pennisetum glaucum (L) R. Br.), Sorghum (Sorghum bicolor (L.) Moench), Fonio (Digitaria exilis Stapf) and the African Rice species (Oriza glaberrima Steud.), and some other crops such as Cowpea (Vigna unguinculata (L.) Walpers.), Voandzou (Vigna subterranean (L.) Verd.) and watermelon (Citrullus vulgaris L.). The Sahel also was a secondary centre of diversification for crops that originated from other continents such as Okra (Abelmoschus esculentus (L.) Moench), Roselle (Hibiscus sabdariffa L.) and Corette (Corchorus olitorius L.). On the livestock side, though zebu cattle originated from the Indo-Pakistan sub-continent, they were introduced long enough to diversify into many famous breeds such as Gobra in Senegal, Maurish and Macina in Mali, Azaouak, Jelli and Bororo in Niger, Gudali and White Fulani in Nigeria, Tchad and Northern Cameroun (Rege, 1996). Mmost of the descendents of the African *Bos Taurus* with center of diversification in actual Sahara have migrated toward more humid zones south of the Sahel where there resistance to trypanosomiasis and to internal and external parasites, allowed for diversification into many local breeds (Ndama, Baoulé, Lagunes, Kapsiki, Namchi, Somba, Muturu). However, one spectacular breed, the Kouri, remained in a peculiar environment in the Sahel; the shore and islands of the lake Chad. Sheep and goats that were probably introduced as early as 5000 years ago from Middle East (Epstein 1971) diversified in an array of wide breeds adapted to particular environment and commodities among which the Red Sokoto goat, the BaliBali sheep, Djalonke sheep and the most famous Macina wool sheep (Wilson 1991). While donkeys originated in Africa, horses and camels were most probably recently introduced into West Africa (Hannote et al. 2000). There is however a large number of camel breeds across the Sahel that has evolved in contact with North African and Middle East breeds covering a wide array of environment and commodity specialisation (dairy, transport, race).

Based on the sole criteria of species richness, the biodiversity of the Sahel flora and fauna appears relatively poor in comparison with other arid or semi-arid systems such as the Karoo-Namib in Southern Africa and the horn of Africa. The level of endemism in the flora as well as the fauna, is very low, the Sahel being considered by bio-geographers a transition zone between the Soudano-Zambezian and the Saharo-Sindian zones of endemism (Aubreville, 1949). The relative poverty of the flora and the paucity of the endemism could be explained by a combination of factors. At macro scale, these factors include the overall uniformity of the climate at the dry end of a monsoonal system, the absence of mountains (only isolated and at the periphery) and the overall similarity of the edaphic conditions based on a geological and paleo-climatic heritage common across very large areas. This overall uniformity associates with the amplitude of the climatic fluctuations during the quaternary, with climates remaining tropical but changing widely, and back and forth, along the arid-humid gradient. At meso-scale, the amplitude variations in rainfall distribution, both across space and over time during the monsoonal wet season, result in large inter-annual changes of the edaphic environment at any given site in the Sahel. Finally, at micro-scale, the redistribution of water by run-off and infiltration, and of nutrients carried by the water, by wind or transferred by the fauna, enhance the diversity of habitats although it does not systematically buffer their inter-annual variations. The long history and macro-scale variability of the environment, relayed by meso-scale edaphic variability did not trigger speciation, but favour species with wide niche that could opportunistically adapt to changing habitats. Except in highly specialised habitat such as wetlands and rocky areas, sahelian species tend not to behave as 'specialists' and take advantage of subtle edaphic trade-offs to establish, some times as dominant or as occasional species, covering a wide range of habitat. This lack of ecological specialisation associated with the amplitude of inter-annual fluctuations, has been a major constraint to fit the successional-climax model of vegetation dynamics to the Sahel vegetation (Trochain 1940, Aubreville 1949) . For the same reason, the phyto-sociologic approach based on ecological specialisation, equilibrium and hierarchical organisation of plant pattern has declined in the Sahel, except in wetlands (Roberty 1940, 1946). The diversity of Sahelian flora does not express in a large number of specialised species but in a limited number of species maintaining a high diversity within (large) populations. For example, this is indicated by the high proportion of genotype diversity explained by within site-population compared to between site populations. The large niche of many sahelian species is based on a genetic diversity within species population maintained by open pollination, this include crop plants such as millet and sorghum.

For the herbivorous animals, additional constraints are imposed by the amplitude of the seasonal fluctuation of feed resources. The long duration and harshness of the dry season, together with the overall poor fertility of the soil contribute to limit the average carrying capacity. The carrying capacity of the Sahel for wild mammals for example is indeed lower than semi-arid zones of East and southern Africa. And mobility is key in this variable environment and this is why the more mobile animal groups, such as the birds, some insect classes, are less affected by the low carrying capacity of the Sahel.

These adaptive traits of the flora and fauna, have conferred on the Sahel ecosystem a strong resilience to abiotic stresses and disturbances, such as droughts, floods and, bush fire although these are most of the time induced by man. The mechanisms of this resilience extend to biotic stresses such as pest proliferations (locust, rodents, granivoros birds) and heavy grazing by wild as well as domestic ungulates. With the exception of the wild mammal populations that were soon decimated due to emergence of slave trade and colonial wars, Sahelian ecosystem remained very variable but resilient as long as the agricultural system remained extensive. However, the unprecedented increase in rural population since mid twentieth century, and the fast build up of urban centres have profoundly changed the land use and challenged the resilience of the system. Following the increase in rural population in the Sahel, lands cropped have expanded by 2 to 4% per annum. Persistent population increase and local migration have resulted in the uneven distribution of the rural population, with hubs in densely populated areas, such as the groundnut belt of Senegal, the Ségou area in Mali, the Mossi plateau in central Burkina Faso, and the Hausa land of southern Niger and Northern Nigeria, separated by more sparsely populated areas (Raynaut, 1997). In the mean time, livestock populations have grown at lower rates (1 to 2%) until the droughts of 1972-1973 and 1983-1984, which led to drastic decline in livestock, especially cattle (Mortimore and al., 2001). The expansion of area cropped together with that of livestock populations have aggravated the shortage of quality grazing resource for livestock in the late dry and early wet season. They also severely increased the grazing pressure on the ranges during the growing season when livestock are excluded from croplands. This increased grazing pressure during the wet season often triggers changes in vegetation composition either to the benefit of short cycle, and thus less productive but generally palatable annuals such as the legume *Zornia glochidiata*, the dicotyledon T*ribulus terrestris* or the grasses *Tragus berteronianus* and *Microchloa indica*, or else benefitthe no or poorly palatable species which are often highly productive such as *Sida cordifolia*, *Cassia tora* and *Hyptis suaveolens* (Hiernaux, 1998). In both cases, these changes result in a reduction of grazing resources. Another risk with the expansion of cropping and the reduction of fallow duration is the fragmentation of the savanna biome that could hinder the capacity of some species to regenerate or propagate and thus lead to progressive loss in genetic diversity. Crop area expansion, and reduction of fallow duration, without increased input in organic matter and nutrients also contribute to impoverishment of soil fertility both by enhancing nutrient exports and by aggravating soil erosion (Manlay et al 2004, Schlecht et al.2004). More modestly, increased grazing pressure also enhances nutrient exports and soil erosion. The slow decline of soil fertility in turns affects the productivity of the vegetation and thus the use efficiency of water and solar energy. The progressive loss of soil fertility and the fragmentation of the landscape converge to erode diversity, either because they lead to disappearance of habitats, or severe reduction in population (i.e. the species remnants are too small and isolated to maintain the specific biomes), or because they promote a few 'invading' species to the detriment of the other (Cassia ssp, Hyptis suaveolens, Sida cordifolia…). All these processes contribute to the downward spiral of desertification.

The main hypothesis is that the desertification trend can be avoided or reversed by adopting resource management policies aiming at both enhancing the resilience of the agro-ecosystem through conserving or strengthening its biodiversity and at improving farmer's livelihood through options to intensify and diversify mixed crop-livestock productions. And there are indeed options for agriculture intensification that would enhance farmer's livelihood and also reverse the trend for environment degradation as enumerated below.

- The first option consists in promoting the integration of cropping and livestock husbandry at all scales from farm up-wards. Expected biological benefits of this integration stems from higher resource use efficiency and functional stability of ecosystem as the trophic systems get more complex . Economy of scale, diversification of products and more balanced labour calendar are the base of the expected economic benefits, while diversification and strengthening of skills, social networks, cultural values should support the social and cultural benefits.
- A second pathway consists in the diversification of crop and livestock production, specially trade-oriented commodities, with a special focus on dual purpose legume on the crop side, poultry and small ruminant on the livestock side.
- The third option consists in promoting the off-farm input such as small amount of inorganic fertilizers, pesticides for cash crops (especially legumes), mineral feed supplement and basic vaccinations of livestock to enhance productivity of targeted commodities. All these can have residual and snowball effects on the ecosystem productivity.
- A fourth option consists in a better integration of woody plant management with both crop and livestock activities, with special focus on the biological, economic, social and tenure aspects of the traditional agro-forestry systems: parkland and field edges.

These options needs to be adapted to each farm type because farming systems are so diverse in terms of access rights, productive assets, labour and skills. . Their adoption and development by farmers entail both social and environmental costs that should be evaluated and discussed among agricultural development partners. There are economic, social and political prerequisite to the adoption and development of these options by the farmers. The use of external inputs as well as the marketing of cash crops, livestock products, wood and related products, depends on the market situation, national and international regulations. Access rights and tenure system depends on social institutions and laws which are in turn influenced by the regional and global political environment.

3. Survey methods

An array of methods have been used from 1994 to 2003 (1994-1998 (funded from ILRI core budget), 1998-2002 (funded by IFAD-IDRC) and since July 2002 (funded by DMP-GEF) to diagnose the agro-ecosystem of the Fakara, verify hypotheses, and test options. They include the followings:

3.1. Farming system survey. Surveys were carried out on household composition, economic activities, cropping and animal husbandry practices, herd composition,. corralling practices, land tenure and genealogy of the families. The summary of these surveys are given below.

- A rapid appraisal was conducted in early 1994 in the selected villages in Fakara to get a first idea of the total population, the proportion of the two major communities (Jerma village farmers and Fulani camp farmers), the livestock population and the distribution of livestock grazing areas among different communities. On the basis of shared grazing territories, villages and camps were grouped into three neighbouring 'sites' named by the name of the main village: 'Banizoumbou', 'Tiguo Tégui' and 'Kodey' (Fig.4)
- A detailed survey was then conducted in 1994 of the 332 households involved enough in livestock production to have distinctive herd management. The farms that had only a few animals such as a few sheep and goats kept for fattening or a couple of oxen kept for animal traction, were not included in the survey. The information included family composition (with the age, sex, and family relationship to the household head), social status and main activities during dry and wet season. Particular emphasis was put on the activities and responsibilities related to livestock management, such as herding during day and night, seasonal transhumance, watering, feeding (supplements), milking and overall herd supervision. Information was also gathered on-farm assets in term of dwelling (location), crop fields, livestock, animal and equipment for traction, and agricultural implements. Each of the crop fields managed by the farm household was identified by local name located relative to geographical units and local toponymy, and documented for history of field, tenure status and crops practices in 1994 and the previous two years. . For livestock, because of the dynamics of herd composition and their seasonal mobility, the description of the herd first done in June 1994 was just the first record of a series repeated about every three weeks till October 1996. The animals managed by each household were subdivided into herd units characterized by the specific herding management (free pasture, herd-release, herded, camp site, departure time from and return time to camp, watering point and timing etc.). Each of these herds was enumerated by a combination of interviews and direct counts.

Table 1. Criteria used to classify animals according to age and physiological status.

Species	Males			Females			
	Calf	Young	Adult	Calf	Young	Cow	
						dry	Lactating
Cattle	unweaned	weaned < 3 years	> 3 years	unweaned	never yet pregnant	dry	Lactating
Sheep	unweaned	weaned < 1 year	> 1 year	unweaned	never yet pregnant	dry	Lactating
Goat	unweaned	weaned < 1 year	> 1 year	unweaned	never yet pregnant	dry	Lactating

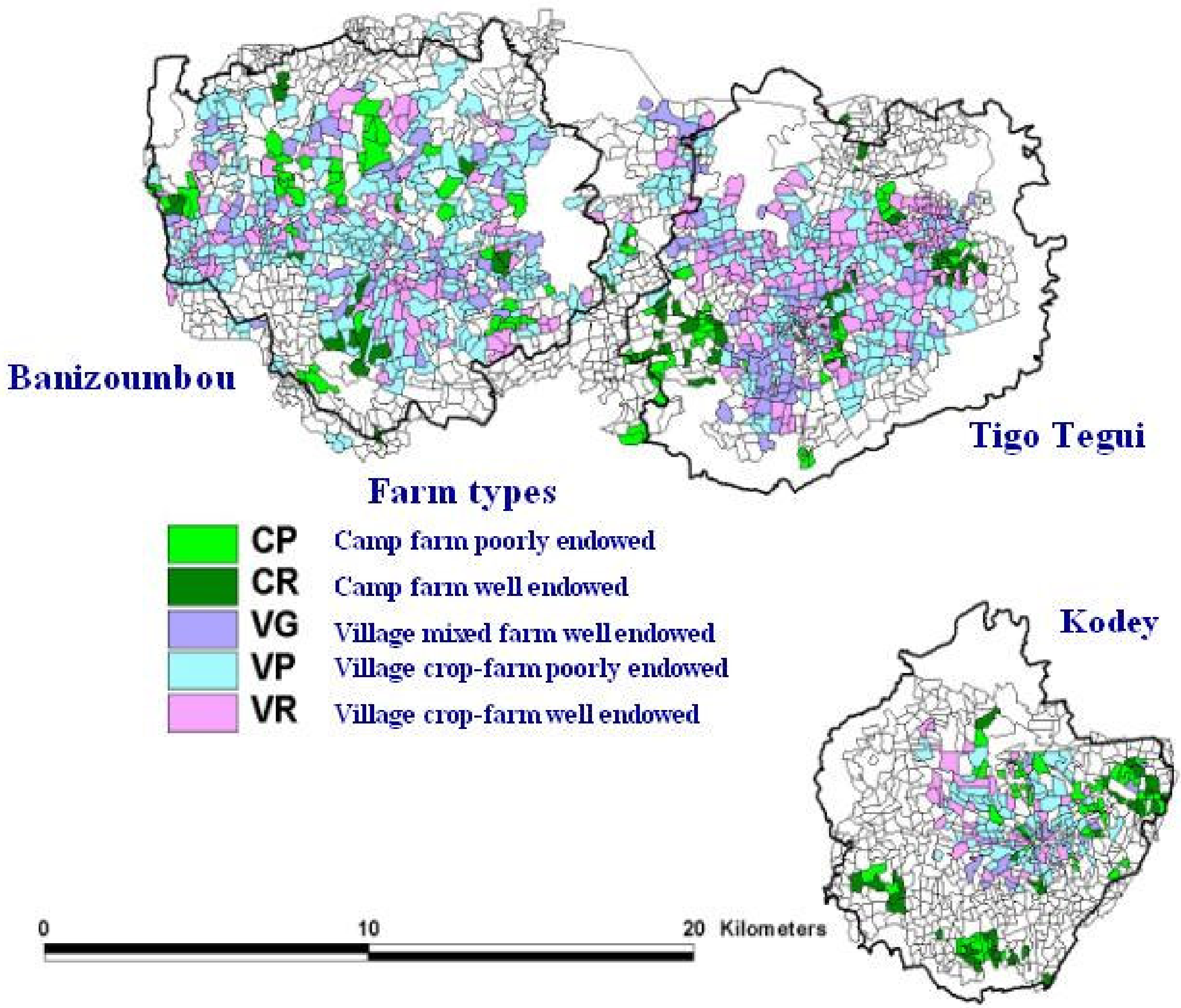
Animals within herds were not individually monitored but categorized with respect to species (cattle, sheep, goats), sex (male, female), age categories (calves, young, adult and in the case of female lactating or dry (Table 1) and ownership status –property of the household, 'talfi', 'habanai', entrusted).

- The exhaustive socio-economic survey of the household was completed in 1997 and extended to all the 532 households within the study area. Information recorded included family composition, economic activities of each individual, crops and livestock management. The survey only covered the households that were managing livestock as in the survey done in 1994.. In order to indirectly assess the area of the crop fields, the proportion of the field cropped was estimated in percent area, and the number of labor-days needed for the first weeding was documented. A sideline survey on 30 fields which area had been measured was used to determine the average labour-days required to weed one hectare of millet field and to estimate the area of the fields. Further information was collected on the soil fertility amendment practices: manure and fertiliser application was roughly quantified. Field tenure was documented and in cases of renting the annual rent, generally in kind, was also estimated.

(Photo Philippe Delfosse)

Photo 5: Fakara landscape seen from a kite: the pool of Bagoua during 2003 wet season.

Figure 4 The three selected sites in Fakara and land tenure for 5 main farm types



- In 2000, an attempt was made to map the land tenure. Each farmer identified the fields his family were managing on the ground, and the fields boundaries indicated by the farmer were reported by the technician directly on the land use map at the scale of 1/15, 000. In view of many changes in land use that had occurred, it is difficult to identify the fields boundaries now with the land use map produced in 1996. An additional survey was conducted in 2002 to document the history of farm settlement, and that of each field from initial cultivation to present status in relation to the family genealogy and ties with other families in the community.
- An additional survey was conducted in 2002 to document the farmer's perception of farm types, and perspectives of their development: targets, technical and institutional constraints. This survey was conducted for each Jerma and Fulani community in the village and was followed by a discussion of the research results.

3.2. Methods used to assess the natural resources and resource use. Base resource information included soil, land-use and vegetation, which were all mapped in 1994 by photo-interpretation of existing 1992 coverages while systematic observations were conducted on sampled sites at the end of October 1994. The mapping was completed by quantitative description of the woody populations of selected sites in 1996

Soils and land use

- The base soil and land use maps were drawn by photo-interpretation of two 1992 aerial coverages: the 1:25000 aerial coverage collected by the Hapex-Sahel Project over the north western part of the study area and the 1:20,000 Canadian-funded IGN mission (IGN NIG 107/200, 13-11-92) on the south eastern corner. Photo interpretation was performed under stereoscope and traced with pencil on overlaid acetate that were digitalized individually under ATLAS-GIS for DOS. To properly join the aerial interpretations in a map, it was found that each photo interpretation needed to be geometrically corrected prior to merging. To perform the correction, GPS readings were taken in at least ten locations within the area covered by each aerial photo. Points were chosen at locations identifiable on the aerial photos as well as on the ground (intersection points between paths, field boundaries, "wadis", and point features such as isolated trees, and wells). At least 150 GPS readings were taken at each point using a Trimble Pathfinder Basic Plus GPS Receiver. The geographic correction was based on the parameters of linear models calculated between the X and Y coordinates of each of these points on the digitized acetate and their longitude and latitude in UTM projection with a WGS-84 datum (Longitude, Latitude = $B_0 + B_1*X + B_2*X^2 + B_3*Y + B_4*Y^2 + B_5*XY$). Generally, common features other than ground control points were found to be separated by 100 meters or less, this is within the range that one would expect for interpretation and digitalisation error.
- Soil resource was mapped considering topography, geomorphology and soil texture. The topographic units identified and mapped were: the plateau with its cliff edge, the sandy upslope locally known as 'plateau skirt' (D'Herbès and Valentin, 1997), the more or less sandy mid- and down-slopes ('glacis'), and the valley bottoms. In each of these, major soil topography classes were further characterised by the morphology and the texture of the top soil considering thick (> 2m) sand deposits or dunes, thin (< 2m) sand deposits, thin loamy sand sediment, erosion surfaces, outcropping hard pan of gravels, valley banks, alluvial plain, levees and channels (Table 2). A correspondence was later established between these soil-map units and the classes of soils either described by soil scientists or by the farmer (Table 3). A survey of farmer's soil classification was conducted in 1998 among 10 Jerma farmers and 10 Fulani agro-pastoralists. The survey also addressed the farmers' perception of the fertility and the management requirement of the soil types, which allowed the grouping of soil units into 5 classes of soil agriculture aptitude (Table 4). To facilitate the use of the maps in

surveys, the local toponymy was indicated based on local place names provided by key informants.

Table 3. Correspondence between soils classifications

FAO soil classification (ISSS et al., 1998)	French soil classification (Gavaud, 1966)	US soil classification (Soil Survey Staff, 1990)
Skeletic leptosol	Sols peu évolués d'érosion régiques à facies ferrugineux	Petroferric Kanhaplustalfs, loamy sands
Ferralic arenosol	Sols ferrugineux peu lessivés, évolués, série très rubéfiée de plateau	Psammentic Paleustalfs, loamy sands
Arenic lixisol	Sols ferrugineux lessivés faiblement différenciés	Pasammentic Haplustalfs, sandy
Arenic cambisol	Sols peu évolués d'apport, facies ferrugineux sur colluvions ,	Psammentic Haplustalfs, sandy
Leptic lixisol	Sols regiques sur gravillons ferrugineux, facies ferrugineux	Petroferric Kanhaplustalfs, Sandy
Gleyic arenosol	Sols ferrugineux lessivés a pseudogley de profondeur	Psammentic Haplustalfs, sandy
Arenic gleysol	Sols hydromorphes a gley sur colluvium des vallées sèches	Aquic Quartzipsamments lsandy loams

These names are associated with ponds, "wadis" or areas ranging in size from fields to large topographic features. For area names, an attempt was made to define their extent with reference to geographical units (see in iv).

Table 4. Matrix of soil agronomic potential defined by the inherent fertility and the physical propriety driving the soil water infiltration

Soil agronomic potential		Water infiltration in the soil (Run-on + permeability)			
		High	Medium	Low	Very low
Soil inherent fertility	Fair	Tv, Rv, Vv	Pd, Td	Pl, Rl	Tr, Rr
	Poor		Rd, Vr, Vd	Pe, Re, Ve	Pg, Pr

- Land-use types in 1992 were mapped with the following distinctions village built area, permanently cropped and regularly-manured fields, other cropped fields, fallows, old fallows and thickets and uncultivable rangelands. In addition, the following features were traced to help identification on the ground (number in bracket after each feature): roads and paths (1306), cattle paths (149), field boundary hedges (2349), isolated trees (9075), camps (208), granaries (571), "wadis" (1514 ephemeral water courses), ponds (261 seasonal ponds), wells and boreholes (38).
- One objective of the mapping exercise was to establish geographical reference to assess the impact of livestock on the agro-ecosystem. It was found that land use units were far too many (2083), with some too small in area and far too dynamic over time (the land use observed in 1994 when doing the photo-interpretation of the 1992 coverage gave evidence of the importance of inter-annual changes) to be used as geographic unit of references. It was thus

decided to delineate ad hoc geographic units that will serve as reference for all resource assessment and monitoring, including the monitoring of livestock movements in the landscape. These geographical units (679, averaging 70 ha in area) were delineated on an overlay on the land use and soil maps, trying to maximise the uniformity of land-use and geomorphology within the units that had to cover a minimum of 10 ha (except for units corresponding to village built areas) with boundaries that had to be easily identifiable on the ground (matching with a path, field hedge, water course). These geographic units were not digitized but added to the map after merging was completed using the "common-border" utility of Arc-Info.

- Sixty map sections of the study area at the scale of 1:15,000 for land use overlaid with local toponymy, and the correspondent 60 map sections for soils, were printed in color and A4 format hard copies to facilitate the survey and monitoring on the ground.

Woody plant vegetation

- Vegetation resources were assessed separately for the two main components: the woody plants and the herbaceous communities including crops. For both woody and herbaceous plants assessments, visual estimates were systematically recorded per land use type within geographical unit, and observations and measures done on representative sampled sites. Visual estimates were also performed in each sample sites and correlated with the measures giving a tool to correct the visual estimates.
- Visual assessment of woody populations per land use type within geographical unit was carried out in 1998. Land use types were grouped into three main categories: cropped land, fallows, non-cultivable rangelands and thickets (although some of them were old fallows). For each land use, several woody population facies could be described. The description was conducted systematically for the two components of the woody population, distinguished by the height of the top of the crown: the trees (> 4 m) and the shrubs (< 4m). Each facies was described by the mean crown cover, mean plant density, and the ranked list of the three species that dominated the total mass of the stand, for trees and shrubs separately. A total of 1025 facies were described. When several facies were described for one land-use type in one geographical unit, the relative area covered by each facies was also assessed (in deciles).
- In 1996, thirty sites were selected based on the topographic position, land-use type, and dominant woody plant species. The sites were preferably selected among the sites where herbaceous vegetation had been already monitored since the onset of the study in 1994. In each of the sites the woody population was described within four circular plots placed systematically along the 200 m axis. The radius of these plots is set prior to data recording in proportion to the density of the woody plant category. The rule of thumb used to determine the plots area was to target the area that would ensure a minimum of 10 individuals within plots. The plots area (Table 5) was thus often different for trees but much less common than shrubs. The species name, total height, width and length of the crown, number and circumference of each trunk near the base, physiological status and evidence of cutting or browsing are systematically recorded for all woody plants encountered within these plots. The circular plots sampling methods was not adapted to assess the contribution of fields hedges, conspicuously a linear pattern, to woody plant population. Thus, in addition to the 30 sites, 12 field hedges were sampled based on the topographic situation and distance from the village. Instead of being circular the plots were linear, following the field hedge with four consecutive segments of 50 m each. The observations and measures on the trees and shrubs recorded along the segments were the same as for circular plots. The mapping of field hedges (soil and land use) was used to extrapolate the results of this assessment at landscape scale. And to avoid double counting, the trees and shrubs from these field hedges were not recorded in the circular plots.

Table 2. Classification of soils by topographic situation, land form and texture of the top soil, that was used to map soils (codes) and correspondence with soils types.

Topography	Land form	Top soil texture	Soil map code	Corresponding soil type	Farmers classifications	
					Jerma	Fulfulde
Plateau	Dune on the plateau	Coarse sands	Pd	Ferralic arenosol	Labu tjirey	Tjayeri
	Thin sand deposit on the iron pan	Sands	Pe	Ferralic arenosol	Gangani	Ferro yorongo
	Ferruginous iron pan outcrop	Rock, gravels, loamy sands	Pg	Skeletic leptosol	Tondi bon	Korkaje
	Thin loamy layer on the iron pan	Loamy sands	Pl	Ferralic arenosol	Gangani	Lisore
	Rocky cliff of the plateau border	Rock, gravels, loamy sands	Pr	Skeletic leptosol	Tondi kaksia	Daga bao
Up-slope	Thick sand deposits	Sands	Td	Ferralic arenosol	Labu tjirey	Tjayeri
	Erosion surface, gullies	Loamy sands, gravels	Tr	Skeletic leptosol	Gangani	Kollade
	Colluvium fan	Sands, Loamy sands	Tv	Cambic arenosol	Tassi kwarey	Tasi Buttiri
Mid and down-slope (embedded erosive surfaces = flats)	Dune on the flats	Coarse sands	Rd	Arenic lixisol	Labu tjirey	Tjayeri
	Thin sand deposits on the flats	Sands, gravels	Re	Arenic lixisol	Gangani	Ferro yorongo
	Thin loamy layer on the flats	Loamy sands, gravels	Rl	Ferralic arenosol	Gangani	Kollade
	Erosive surfaces outcrop	Gravels, loamy sands	Rr	Leptic lixisol	Gangani	Kollade
	Depressions filled with colluvium	loamy sands, sands	Rv	Arenic cambisol	Tombo	Lisore
Valley System	Major river bed or valley banks	Sands	Vr	Arenic lixisol	Tassi Kwarey	Tasi buttiri
	Minor river bed banks	Loamy sands	Vd	Arenic lixisol	Botogo tjirey	Lope bodejo
	Fossil alluvial plain	Sands, leached	Ve	Gleyic arenosol	Tasi kwarey	Tasi buttiri
	Fossil levees	Loamy sands, leached	Vl	Gleyic arenosol	Bulungu	Bulunguri
	Fossil canal and river beds	Loamy sands, clayed loams	Vc	Arenic gleysol	Botogo bi	Lope baledjo
	River bed	loamy sands, clayed loams	Vv	Arenic gleysol	Botogo bi	Lope baledjo

Table 5. Size of the plot area used to record the components of woody plant population. Observations were done on 4 circular plots along a 200 meter axe for the 31 sites in Fakara.

Site code	Facies	Plot area (m²) Dominant shrubs	Other shrubs	All trees	Site code	Facies	Plot area (m²) Dominant shrubs	Other shrubs	All trees
B17	1	314	1257	3927	KK15	1	314	1257	3927
B24	1	314	1257	3927	KZ7	1	314	1257	3927
BZ19	1	314	1257	3927	MZ6	1	314	1257	3927
BZ34	1	314	1257	3927	ND2	1	314	1257	3927
BZ37	1	314	1257	3927	TA13	1	314	1257	3927
BZ39	1	314	1257	3927	TK2	1	314	1257	3927
G13	1	314	1257	3927	TK21	1	314	1257	3927
GY15	1	314	1257	3927	TK26	1	134	616	-
K2	1	314	1257	3927	TK26	2	-	1257	3927
K21	1	-	154	616	TK28	1	134	616	-
K40	1	-	154	314	TK5	1	314	1257	3927
K40	2	314	616	-	TT16	1	314	1257	3927
KA10	1	314	1257	3927	TT9	1	314	1257	3927
KA18	1	314	1257	3927	TZ19	1	314	1257	3927
KA4	1	314	1257	3927	TZ2	1	314	1257	3927
KA8	1	134	616	-					

Dominant shrubs were: Guiera senegalensis and Combretum micranthum in TK21, BZ37 and KA8; Combretum glutinosum in KA18 and TT16; Guiera senegalensis in all other sites.

- Statistics on population density, crown cover and basal area were calculated from the records for each species, trees and shrubs, and for all woody plants at each site. Leaf and wood masses were also estimated for the same categories at each site. These estimates relied on exponential relations established by destructive sampling for each species (Cissé et al. 1980) between the base circumference of each individual trunk and the mass of leaves, as well as that of different categories of wood (main trunk, large branches, small branches and twigs).

Table 6. Parameter of linear regressions between the foliage mass (in kg DM ha^{-1}) of sampled trees (n=27), shrub (n=31); and total woody plant (n=31) populations and their density, crown cover and basal cover in 31 sites in Fakara, western Niger (for all regressions P>F was < 0.0001).

		Plant Density (m^2 ha^{-1})	Crown cover (%)	Basal cover (m^2 ha^{-1})
Trees:	Slope	2.25	37.30	146.50
	s.d.	0.09	0.88	3.70
	r^2	0.96	0.98	0.98
Shrub:	Slope	0.59	26.59	52.60
	s.d.	0.05	1.42	2.80
	r^2	0.83	0.92	0.92
All woody plants:	Slope	0.88	30.56	72.40
	s.d.	0.04	1.34	4.10
	r^2	0.95	0.94	0.91

Regressions between crown cover estimates and leaf or wood masses were then used to assess the leaf and wood masses of the woody plant facies described over the whole area and for which tree and shrub crown cover had been visually estimated (Table 6 and 7). The contribution of the dominant species to plant density, basal area, crown cover, leaf and wood masses were systematically calculated at each site. And their statistics were used to weight the contribution of first, second and third dominant species in the tree and the shrub community of the described facies. The weighting factors used for the contribution of dominant species to the leaf mass of trees were 65, 20, 5%, and 10% for the first, second, and third dominant species, and other species, respectively. For shrubs, the values were 75, 15, 5 and 5% for the first, second, and third dominant species, and other species, respectively.

Table 7. Parameter of linear regressions between the total wood mass (in kg DM ha^{-1}) of sampled trees (n=27), shrub (n=31); and total woody plant (n=31) populations and their density, crown cover and basal cover in 31 sites in Fakara, western Niger (for all regressions P>F was < 0.0001).

		Plant Density (m^2 ha^{-1})	Crown cover (%)	Basal cover (m^2 ha^{-1})
Trees:	Slope	37.40	626.30	2449.60
	s.d.	2.70	27.80	119.9
	r^2	0.91	0.95	0.94
Shrub:	Slope	6.20	272.40	537.8
	s.d.	0.44	14.30	28.6
	r^2	0.86	0.92	0.92
All woody plants:	Slope	11.70	400.00	935.6
	s.d.	0.63	26.80	78.1
	r^2	0.92	0.88	0.82

Herbaceous plants

- The methods used to assess the resources of the herbaceous vegetation including crops, also combined systematic visual estimates, and sample sites observations and measures, both of which were carried out at the end of the growing season. Visual estimates are performed per land-use type within geographical unit. For uncropped lands, visual estimates were performed per facies of herbaceous vegetation within geographical unit together with a visual estimate of its relative area occupied by the facies within that geographical unit. Similarly, weed facies were described and their relative area within croplands estimated. In addition, crops were stratified in four categories based on the use of manure, while for the non-manured fields the four categories were based on the density and height of the millet or sorghum plants (Low, Medium and High). Visual estimates for each herbaceous or weed facies consists in a ranked list of the three species which dominate in the standing mass, the distribution of the standing mass expressed in number of deciles in nine preset classes (0; <125;125-250; 250-500; 500-1000; 1000-2000; 2000-4000; > 4000 kg dry matter per hectare), and distribution of grazing pressure during the growing season. The distribution of grazing pressure is also expressed in number of deciles in four classes namely no grazing, light (1/3 of standing mass), moderate (2/3 of standing mass) and intense grazing (grazed fraction equivalent to standing mass).

- In October 1994, 24 cropland and 24 fallow-rangeland sites were sampled across the study area in the four types of crop fields described above, and in the main types of fallow and un-cultivable rangelands, depending on soil types and dominant species. Observations and measures were conducted at the end of the growing season and just after grain harvest in the case of crop fields, along an identified axis of 200m long in fallow-rangelands and 100m in croplands. In fallow and rangelands, the herbaceous layer was then stratified into four classes of apparent and relative herbaceous density: bare soil, low, median, and high densities. The description of species composition includes the exhaustive list of species observed in 1m² square plots (12). The standing mass of the herbage is then measured destructively in each of the twelve plots located following random-stratified sampling along the 200 m transect. The distribution of the plots in strata was set at 3 in low and high, and 6 in median strata (Hiernaux 1995). Relative areas of strata within site were estimated by counting their occurrence within 200 square meters along the axis. These frequencies were then used to weight the mean cover and masses per strata (herbage mass and cover were set to null in the 'bare soil' strata which was not sampled). These frequencies were also used to weight the contribution of species to the weighted mean cover (table 8).

Table 8. Visual estimate of the standing and litter mass of the herbage layer. Classes of herbage mass (kg dry matter ha^{-1}) and example of calculation of the herbage mass in a fallow site in Gourou Yena, in February 1996. The regressions established in February 1996 from 25 sites including the example were for standing herbage: awm[1]= 1.326 wm[2] (s;e. = 0.088); for litter: awm = 2.132 wm.(s.e. = 0.183).

Class	lower limit	higher limit	class median	Example (site GY9.1996)				
				Standing[a]		Litter[a]		Total above ground herbage mass
0	0.0	62.5	31.25	0.1	3.12	0.1	3.12	
1	62.5	125	93.75	0.2	18.75	0.4	37.5	
2	125	250	187.5	0.2	37.5	0.3	56.25	
3	250	500	375	0.2	75.0	0.2	75.0	
4	500	1000	750	0.2	150.0	0.0	0.0	
5	1000	2000	1500	0.1	150.0	0.0	0.0	
6	2000	4000	3000	0.0	0.0	0.0	0.0	
7	4000	8000	6000	0.0	0.0	0.0	0.0	
Total and weighted mass (wm)				1.0	434.4	1.0	171.9	606.3
Adjusted weighted mass (awm) s.e.					576.1 . 38.1		366.4 . 31.5	942.5 . 101.8
Above ground mass measured in the field					518.1		461.1	979.3

[1] awm refers to average weighted mass; [2] wm refers to weighted mass.
[a] values in first column are class frequencies while values in second column are class weighted masses

- In cropped fields, weeds were also samples in 1m² plots, with species list and destructive measure of mass done for each of 10 plots placed every 10 m along the 100 meters axis. It was thought that because of relative homogeneity of weed populations, stratification was not needed. The mass of the crop stalks or residues was estimated by determining the density of the crop plant in the selected site and sub-sampling ten of these plants (the nearest to the point every ten meters on the axis). The crop density was estimated by measuring the distance of the nearest plant (separately for each cropped species in associated cropping systems) to points on the axis (one every 10 meters) within a four quadrant defined by the axis and its perpendicular at the height of the point. These distances were averaged per point and along the axis (md). The density is estimated by the inverted root square of that mean multiplied by the unit area (density = 10 000*($md^{-0.5}$); md is in meter and density expressed per hectare). In the case of millet, grain yields were indirectly estimated based on harvest ratio measured on fields representative of the different types.

Table 9. Coefficient of regression or slope of the regression line established between measured (dependent) and estimated values of weed mass in croplands monitored in the Fakara region (western Niger) from October 1995 to October 1999.

Date	Herbaceous type	n	Slope		r^2	P
			Estimate	s.e.		
July 1994	all	4	0.54	0.07	0.95	0.0001
October 1994						
February 1995	all	25	1.85	0.15	0.87	0.0001
June 1995	standing	25	0.89	0.18	0.53	0.0001
	litter	25	1.68	0.22	0.72	0.0001
October 1995	standing	16	1.68	0.15	0.89	0.0001
February 1996	standing	25	0.52	0.05	0.80	0.0001
	litter	25	0.88	0.12	0.72	0.0001
June 1996	standing	24	0.53	0.06	0.75	0.0001
	litter	24	0.87	0.17	0.54	0.0001
October 1996	standing	18	1.71	0.14	0.89	0.0001
October 1997	standing	23	1.60	0.23	0.68	0.0001
March 1998	standing	25	0.85	0.09	0.79	0.0001
	litter	25	0.88	0.10	0.77	0.0001
October 1998	standing	24	1.01	0.07	0.90	0.0001
October 1999	Standing	11	1.32	0.13	0.91	0.0001

- Visual estimates of standing herbage mass, grazing pressure intensity and list of first three dominant species were also carried out for herbaceous or weeds at each sampled site so that a regression could be established between the measured and the estimated masses (Table 9). The regression coefficient was then used to correct the visual estimate of standing mass per herbaceous or weed facies. The species contribution of plant cover was also calculated for each of the three species designated as dominant. The mean value across sites of the plant contribution to cover were calculated for the first, second and third dominant species, as well as for ‘all other species’ separately for fallow-rangeland and crop-field weed. These statistics were then used to weight species contribution to vegetation standing mass in herbaceous and weed facies allowing estimates of dominant species contribution to herbaceous communities at landscape scale.

Table 10. Coefficient of regression or slope of the regression line established between measured (dependent) and estimated values of herbage mass in rangeland and fallows monitored in the Fakara region (western Niger) from July 1994 to October 1999.

Date	Herbaceous type	n	slope S in: mass = S (estimated mass)		r^2	P
			Estimate	s.e.		
July 1994	standing	19	1.25	0.14	0.83	0.0001
	Litter	19	1.62	0.13	0.90	0.0001
October 1994	standing	25	1.47	0.07	0.95	0.0001
February 1995	standing	26	1.50	0.09	0.93	0.0001
	Litter	26	1.62	0.18	0.76	0.0001
June 1995	standing	23	1.06	0.10	0.83	0.0001
	Litter	23	1.60	0.20	0.74	0.0001
October 1995	standing	12	1.36	0.12	0.92	0.0001
February 1996	standing	25	1.33	0.09	0.90	0.0001
	Litter	25	2.13	0.18	0.85	0.0001
June 1996	standing	25	0.67	0.05	0.87	0.0001
	Litter	25	1.74	0.17	0.81	0.0001
October 1996	standing	25	1.64	0.10	0.92	0.0001
October 1997	standing	25	1.62	0.09	0.93	0.0001
March 1998	standing	21	1.13	0.07	0.92	0.0001
	Litter	21	2.13	0.16	0.90	0.0001
October 1998	standing	21	1.59	0.11	0.91	0.0001
October 1999	standing	12	0.95	0.09	0.90	0.0001

3.3. Resource monitoring and impact assessment. The seasonal and inter-annual dynamics of natural resources in relation to climate and management were assessed by systematically repeating map and field measures. Particular attention was put in assessing the seasonal changes in livestock feed resources and the impact of crop and livestock management on these changes in resources.

- Only 5 rain gauges were set in Fakara and monitored prior to the 90's. However, a very dense web of rain gauges (107 sites within Niamey degree square) and 12 fully equipped weather stations were set within Fakara for the sake of EPSAT study of rainfall distribution, and low atmosphere processes within the international Hapex-Sahel project (Lebel et al. 1997). The project only lasted two years but the network of rain gauges and some weather measures were maintained by IRD projects for a few more years. An automatic photometer which measures are used to assess the density of aerosols in the atmosphere was also put in place close to the village of Banizoumbou in the Fakara by IRD. Then, since year 2001, a new network of rain gauges and two automatic weather stations were put in place by ICRISAT in order to monitor the agro-climatic conditions in the Fakara. The data are collected on a regular basis by farmers and technicians, and fed into a GIS.

- Land use was mapped in 1994, 1995 and 1996 using aerial photos taken with a 24x36 mm camera from a small aircraft flying at 1200 m altitude. Photo-interpretation under stereoscopy as done for the 1992 coverage was performed to map land use in 1950 and 1975 using exiting coverages (IGN). Same categories of land use were considered as for 1992 mapping (village built area, permanently cropped and regularly-manured fields, other cropped fields, fallows, old fallows and thickets and uncultivable rangelands) except for the maps of 1950 and 1975 for which, in addition, lands that had no sign of past cropping history were mapped as 'pristine savannas'. Since 1994 (with exception of 1999 and 2003) visual estimates of the relative size of each land use type (crop, fallow, thicket, rangeland) and each crop type within cropped area (low, median, high density in un-manured fields, manured fields) were conducted per geographical unit over the whole area.
- The seasonal dynamics of the herbaceous vegetation was documented by repeating three times a year the visual estimates at landscape scale and the measures conducted on the sampled sites on croplands as well as fallows and rangelands. These measures were carried out in late October (the end of the wet season), in late February (mid dry season when the weather is relatively cool and most of the crop residues left in the field have been grazed and when field preparation for the next wet season begins). The third measure was carried out in late June (the end of the dry season, or sometimes just after the first rains), to assess what was left of the herbaceous vegetation at the end of the dry season and the onset of the new one (Table10).

Table 11. Herd sampling for behavior monitoring per species, season and type of herding from July 1994 to October 1996

Species	Season	Management (number of herds monitored)			
		Full herding	Partial herding	Free grazing	total
Cattle	Early dry	37	3	0	40
	Mid dry	34	9	3	46
	Late dry	36	5	1	42
	Early wet	19	0	0	19
	Late wet	16	0	0	16
Goat	Early dry	20	14	1	35
	Mid dry	5	29	1	35
	Late dry	3	28	1	32
	Early wet	10	0	0	10
	Late wet	14	0	0	14
Sheep	Early dry	20	5	0	25
	Mid dry	28	12	0	40
	Late dry	18	10	1	29
	Early wet	5	0	0	5
	Late wet	12	0	0	12

Species composition was only recorded in October as no changes are expected to occur during the dry season and identification of species is more tedious. On the other hand, litter was systematically assessed and measured separately from standing material, for rangeland herbaceous as well as for weed and crop residues in fields.

- The inter-annual dynamics is documented by the repetition over years of the assessment done at the end of the growing season. Visual assessments were repeated every year since 1994, except 1999 and 2003, while observations and measures at sampled sites were done systematically from 1994 to 2003. Because of change in land use of some of the sites, the monitoring has not been always done on same sites. Indeed sites were added along to keep the balance between edaphic situations within each land use type. From 48 at the onset of the monitoring in 1994 the total number of observation sites reached 65 in 2003. At most, measures were carried out every year in 48 sites (24 crop fields and 24 fallow-rangelands) but at least the type of land use and of grazing pressure were recorded on all sites, and photos were systematically taken to document the dynamics of land use. The observed changes of land use over the 10 years were used to verify fallowing models.
- From April 1995 to June 1996, the grazing and excretion behavior of cattle, sheep and goats were studied in selected herds from the three study sites in Fakara. Herds were selected following a random- stratified sampling based on their size and type of herding (fully herded, herded part of the time, free grazing). The sampling was repeated independently at each season determined by climate and access to forage resources. The 'wet season' is from mid-June to mid-October, during which grazing livestock had no access to the cropped fields. The 'early dry' is from mid-October to mid-December, 'mid dry' from mid-December to mid-March, and 'late dry' from mid- March to mid-June (Table 11). Each herd was physically monitored for one day per season during which two types of observations were carried out independently by two observers. One observation consisted in recording the location relative to land use and geographical unit and behavior of a selected animal every 5 minutes (Schlecht 1998). This observer had also to record the time and location of all the fecal and urine excretions of the selected animal. For behavior, distinctions were made between grazing, browsing, walking between feeding stations, walking for longer distances, drinking, resting and ruminating, either standing or laying down. However, in the data analysis, activities were grouped in three main categories: grazing that includes browsing and walking between feeding stations, walking and resting which includes all the other activities listed above. The second observer attempted to record the time of all fecal and urine excretions of any animal of the herd that he considered visible during that period of time. The number of visible animals was also recorded when changes occurred in the position of the herd relative to landscape and to other herds. In most cases the two types of observations were carried out simultaneously (Table 12) allowing the analysis of herd excretion events relative to the excretion behavior observed for one animal of the herd. To reduce the risk that the instantaneous activity of one animal might not be representative for the general activity of the herd, behavior data were smoothed. Smoothing consisted in characterizing the activity at each five minutes by the dominant activity within the 25 minutes that followed the observation, i.e. identifying the most frequent of the three main activities among the 5 subsequent observations.

Table 12. The number of herds monitored and the type of monitoring per season and per year[a]

	Type of monitoring	Early Dry	Mid Dry	Late Dry	Wet	Year Total
Cattle	Behavior of 1 animal	45	47	43	36	171
	Excretions monitored	35	34	27	23	119
	Both simultaneously	27	33	26	22	108
Sheep	Behavior of 1 animal	29	42	29	20	120
	Excretions monitored	24	31	16	11	82
	Both simultaneously	20	30	16	8	74
Goats	Behavior of 1 animal	40	40	34	27	141
	Excretions monitored	26	32	19	16	93
	Both simultaneously	21	27	17	14	79

[a] Grazing behavior were recorded every 5 min on one selected animal for which excretions are also recorded while excretions were recorded for all visible animals of the herd

Then, periods where the same activities dominated - grazing, walking and resting - were defined by their starting and ending time. The merging of this simplified behavior timing data with the excretion timing data allowed the calculation of excretion frequencies (expressed in number of excretions per animal and per hour) during each dominant animal activity. Similar calculations were done for excretions occurring during watering (one or two times per day with a few exceptions of animals not watered during the wet season), and during the first, second and third period of 15 minutes that followed either morning departure from the corral, watering, or any period of rest.

- In 1998, corralling practices were monitored over a full year cycle all over the study area. For each farm that applied manure by corralling livestock on fields (dry season) or on fallows (wet season) corral spots (3973) were localised, relative to geographical unit but also distance from village or from camp. The area of each spot was measured, and the number and type of animals recorded as well as the starting and ending dates of the corralling on this spot. On a sub-sample of 60 corral spots, the mass of faecal excretion as well as that of other organic material (crop residues) was assessed just after corralling and their fate was monitored during the rest of the year. The soil of the corralling spot was also sampled to assess impact of corralling on soil organic matter, pH and nutrient contents.

4. Experimental methods

4.1. Since 1994 and more importantly since 2000, trials have been conducted by ILRI, often in collaboration with other research institutes (INRAN, ICRISAT, IFDC, FAO) to test with farmers alternative management technologies for livestock production (mineral, protein, or energy supplements, fattening diets, transhumance). For grazing methods, impact of grazing management on livestock performance, range production, rangeland species composition and soils were tested. For livestock-crop interaction related to animal feeding and soil fertility management, use of crop residues and by products as animal feed or as mulch, manure amendment (especially by corralling), and enhancing cowpea in associated millet-cowpea crops were tested. Most trials were conducted in farmer's fields from Fakara villages and camps. However, some companion experiments that required higher level of control were carried out in the research station of ICRISAT, at Sadoré.

Experiments on livestock feeding

- The effects of dry season supplementation were evaluated on dairy cow productivity for cows that were sent on transhumance during the wet and early dry seasons or cows that were sedentary in the village all year round. The objective was to assess the interactions of supplementation with the practice of transhumance. This study was initiated in 1998 in the village of Katanga (2º48 E, 13º32 N) with 60 heifers and extended in 1999 to include 45 more heifers in the village of Gorou-yena (2º44 E, 13º30 N). In 2002, the first herd completed the fifth cycle of transhumance while the second completed its fourth transhumance cycle. In both herds, cows were allotted to six treatments in a factorial arrangement of three levels of dry season supplementation (including 0, 360 and 720 g of millet bran equivalent to 333 and 666 g dry matter per cow per day. Simple super phosphate were added to the supplements at the levels of 0, 2 or 4g per heifer per day, respectively 360 g of millet bran provided about 50 g crude protein and 3 MJ metabolisable energy. Response variables measured included yearly and seasonal weight changes, body condition scores, faecal concentration of OM, N and P, calving and weaning rates, birth and weaning weights, weight changes of calves before weaning, and milk production of the lactating cow (during the early dry season, at the return from transhumance only). All animals were vaccinated against Pleuropneumonia, Anthrax, and Pasteurelosis once a year and treated against external and internal parasites and other infections. The manure collected in these trials was used to test the influence and quality of manure on millet yield. An economic evaluation was also attempted.
- Considering the potential importance of sheep fattening as a source of cash for poor farmers of the Fakara but also the very large variability of economic profitability of sheep fattening in Niger, trials were conducted for three years with 18 farmers of 4 villages in the Fakara aiming at testing alternative cheap fattening diets. Each farmer fattened four sheep during two months with diets composed of 300 g of millet bran, ad libitum bush hay and different levels of cowpea haulms ranging from 0 to 900 g d^{-1} per animal. All animals were vaccinated and treated against internal parasites. Their weight was monitored as well as feed intake and excretion. An economic evaluation was also conducted, based on buying and selling price by the farmer and the cost of the diet.

4.2. Experiment on alternative grazing methods, and evaluation of livestock grazing impact on livestock performances and rangelands. Because the test of alternative grazing methods require a control of the timing and intensity of grazing over long periods these tests have only been carried out on-station in Sadoré. The limited size of the rangelands in the station limited trial objectives to the study of processes. Impact of alternative grazing systems (stocking rates, animal species mix, rotation and deferred grazing) on livestock performance was only possible for small ruminants, while impact on soil and vegetation was also studied for cattle.

- The impact of stocking rate (equivalent to 0, 0.25 and 0.5 Tropical livestock unit per hectare over the year) with sheep and goats, either in pure flock or mixed was tested from 1993 to 1996 on fallow vegetation grazed year-round in Sadoré. Effects were measured on animal live weight changes, feed intake and excretions, changes in herbage mass and species composition.
- The impact of alternative rotation grazing, and deferred grazing by sheep and goat mixes was tested from 1996 to 2002 on old fallows in Sadoré. Animal weight changes and excretions were recorded, and the effects on herbage production, species composition and soil properties were measured.
- The effect of seasonal grazing by cattle on a young fallow in Sadoré. Cattle were grazed at the stocking rate of 0.5 TLU per hectare either every two weeks in the wet season, or only during the dry season, or in both seasons compared to the effect of full protection from grazing. Animal weights were recorded, and the effects of grazing were measured on herbage mass, production, species composition and soil seed stock dynamics.

4.3. Experiments on soil fertility management technologies. Soil fertility appeared to be the first limiting factor of crop productivity, and a major constraint to intensification of the agricultural system altogether. However, soil fertility situations differ widely across fields and across farm. Both livestock manure and crop residues play a key role in soil fertility management and there are trade-offs between the alternative uses of crop residues as mulch or as livestock feed depending on the farm assets in croplands and livestock. General soil deficiencies in nitrogen and phosphorus are recognised, and the recourse to N and P inorganic fertilisers advocated for long. However, the high cost of fertilisers and the difficulty of access have hindered farmers to use fertiliser, except for very small amounts mostly applied on cash crops. Alternative use of small doses of mineral fertilisers, mainly P, placed at the plant hills have been advocated and tested successfully (Buerkert 1995) but its profitability is still marginal thus limiting adoption. There are synergies and trade-offs between placed application of small doses of P fertiliser and organic amendments that may reinforce and extend over time the impact of the fertiliser input, and thus increase profitability. Experiments were developed to try and assess these interactions. Most of the experiments were carried out on farmers' fields in Fakara (with a full range of approaches from a scientist run to farmers run trials). However, companion trials were also carried out at Sadoré research station when the complexity of the protocol or the duration of the experiment (measure of residual effect over several years) required a level of control difficult to ensure in village situation because of communal use of crop residues. The manuring trials are briefly described below:

- Manuring trials in the Fakara were associated with cattle feeding or transhumance experiments and were initiated in farmers' fields in 1998 and 1999. The objective of these trials was to compare the effect of excretions produced by supplemented animals with those that were not supplemented. Heifers received N and/or P supplements as urea in drinking water or phosphate mixed with 'natron' (local salt licks). The manure of heifers receiving different mineral or energetic supplements was 'harvested' by corralling the animals at night on fields where millet is subsequently planted. The rate of manure application resulting from the corralling practice was generally set at 6t DM ha^{-1}, with non manured control plots. The effect of supplementation was also compared with direct applications of urea and/or phosphate to the plant with or without addition of millet stem litter. The experiment carried out in 1998 was repeated on a second field in 1999. Amendment effects were measured on stalks and grain yield of millet planted at 10,000 hills per hectare, as well as on the N and P concentrations in the rainy season following the treatment but also in the following years to assess the residual effects. The fourth year after corralling, the residual effect was completed by the application of placed NPK fertilizer at 2 kg P_2O_5 ha^{-1} in 2 out of 4 blocks in order to test relay combination of organic and small doses of placed inorganic fertilizer. Changes in organic matter, N and P contents were also monitored at soil surface and in the top soil.

- The effects of manure produced by heifers fed different quantities of millet bran supplement and phosphate during the dry season on subsequent millet crop were measured in another experiment initiated in 1999 in a farmers field in the village of Katanga and repeated thereafter in 2000 and 2001. The trial included 4 manure rates (0, 6, 12 and 18 t DM ha^{-1}) combined in a split plot design with placed inorganic fertilizer (4 kg of P ha^{-1} as NPK 15-15-15). Each treatment was replicated 4 times. Again, amendment effect was measured on yields and nutrient concentrations. Changes in organic matter, N and P contents were also monitored at soil surface and in the topsoil.
- The effect of alternative bedding material at the corral stops were tested in two experiments. One was carried out in 1998 in a farmer's field at Boundou (using millet stalks, grass straws or *Guiera senegalensis* leaves as alternative bedding material) and the other one was initiated in 2000 in farmer's field in Gourou Yena (using millet stalks and branches of *Guiera senegalensis as bedding*). In both cases, different rates of manure application by corralling or by hand application were applied (Boundous experiment, Sangaré et al. 2002). The effects were measured on millet yields and N and P concentration, and also on topsoil pH, organic matter, N and P concentrations.
- Controlled experiment was carried out on-station in Sadoré to assess the impact of rate of manure application on soil fertility, nutrient cycling and use efficacy by millet crop in the year after corralling and the four following years.. The trial was initiated in 1997 and it was repeated on another field with one year lag. The trial was carried out for 5 years on each field. In addition to the effect of the rate of manure application (0, 2, 4, 6, 10, 14 t DM ha^{-1}), the factorial trial design allowed the assessment of the effects of the quality (cattle/sheep-goat excretions) and timing of application (five seasons: early wet and late wet, early, mid and late dry seasons) of faeces and urine by corralling either cattle or sheep and goats on a field either formerly cropped with millet or on a young fallow. In addition to measuring millet yields and nutrient uptake by millet, the decomposition of the millet litter and the faeces deposited by cattle, sheep and goats were monitored as well as their changing chemical composition. Soils were regularly sampled - soil moisture profile was monitored using neutron probes (0-6m) and capacitance probe (0-1.8m) in selected treatments. Nutrient leaching was also assessed at monthly intervals (NO_3) or at the onset and the end of the growing season (organic C, exchangeable bases, P) by destructive soil sampling.
- To verify previous experimental results obtained under different conditions (Brouwer and Powell 1995; Somda et al. 1995), another corralling experiment was

conducted in controlled condition at Sadoré. This experiment, which was initiated in 2001, aimed at assessing the respective contributions of urine and faeces to the fertilization effect of night corralling by either cattle or sheep-goats (four rates of application equivalent to 0,6,12,18 t DM ha^{-1}). The assessment was carried out with male animals fit with faecal collection bags in order to separate faeces from urine. The separate application was also compared to joint application, and this is repeated at three levels of application and to unmanured controls. The effects were measured on millet grain and stalk yields as well as on soil pH, organic matter, P and N contents.

- To examine how small amounts of placed inorganic fertiliser (DAP or NPK) could interact with the residual effect of manure application by corralling, additional experiments were conducted in controlled condition at Sadoré. The intent was to provide additional information on appropriate fertilizer rates to be applied by farmers who practice crop-livestock farming. A second objective was also to fine-tune the micro-dose technology that had already been tested and promoted to farmers by ICRISAT-IFDC-University of Hohenheim-ILRI and FAO.

4.4. Experiments on cow-pea cropping

- In the farmers field in Fakara, a controlled experiment was conducted from 1999 to 2001 to evaluate cowpea breed accessions and management options for millet-cowpea intercropping. The experiment was based on a randomized split-split-plot design with main plot being NPK hill-placed in the millet and cowpea rows, subplot being the timing of broadcast of crop residues application and the burial of crop residue in ridges, and sub-sub plot the level of crop residue. Ridging with incorporated crop residue was implemented strictly in the cowpea row. Millet and cowpea were sown in alternate rows at a density of 6666 hills/ha. Response variables included yields of millet and cowpea and yield components, soil chemical quality and nutrient uptake by the crops.

(Photo P. Hiernaux)

Photo 6 Cattle herd corralled in a millet field after harvest, Lellehy, western Niger

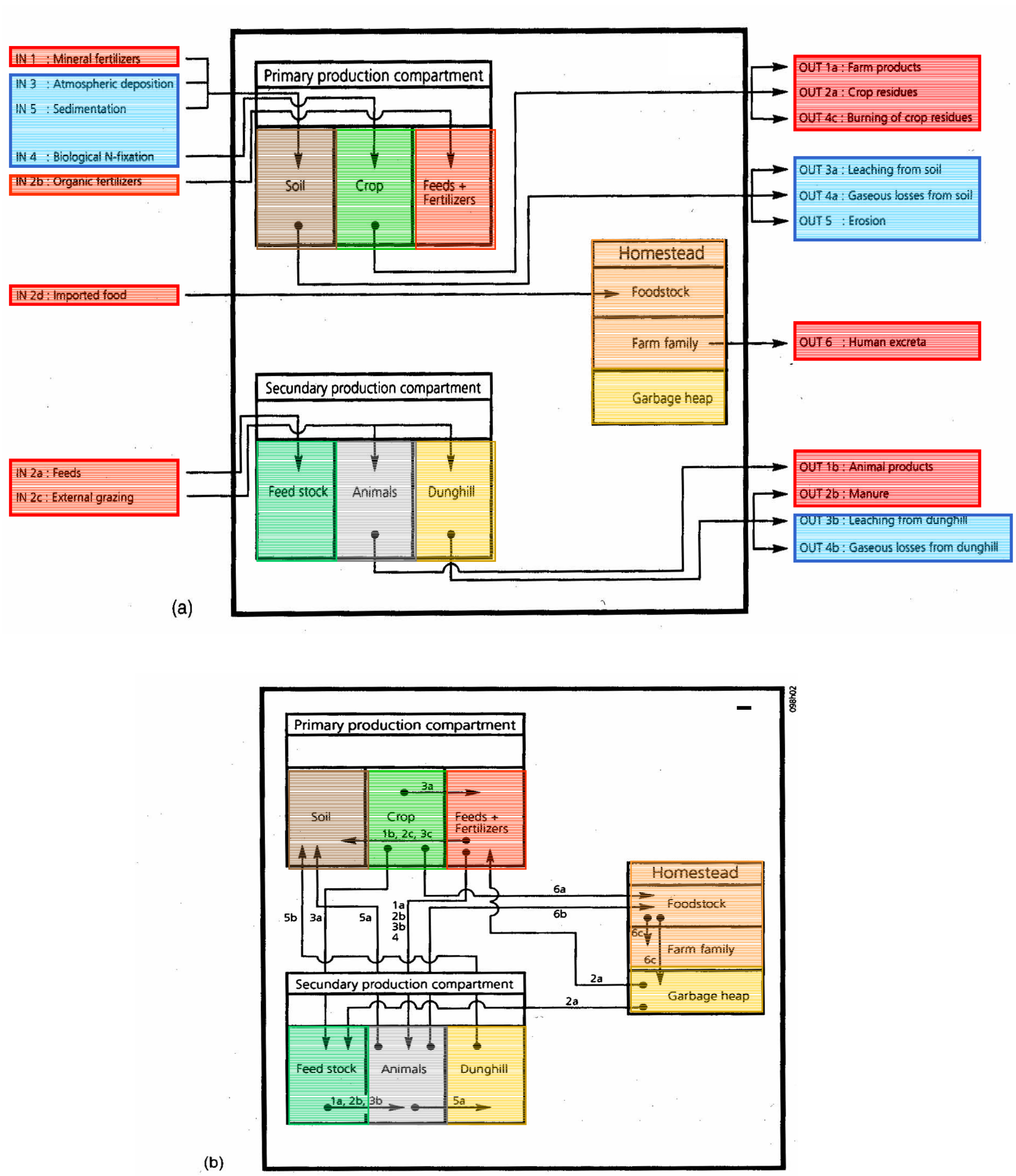
5. Agro-ecosystem modelling

5.1. The complexity of the agro-ecosystem, with multiple interactions between climatic, biological and socio-economic processes, at different spatial and temporal scales calls for an adapted modelling tools to assess the impact of policies and technologies interventions in reversing the trend of desertification in an agro-ecosystem under stress such as in the Fakara. Several attempts were made to adapt existing tools using the Fakara farm database.

- An existing bio-economic model at the village community scale by B. Barbier (1998) was adapted and tested using Fakara farm database. The model was used to simulate the long-term consequences of changes in population growth and reduced access to grazing areas on the economic performance of the farmers, population demography and migrations. Particular attention was given to the role of drought risks in conditioning the model's results (Barbier and Hazell, 2000). Biological processes, crop and livestock production were however very coarsely simulated and the model did not consider the unequal access of farmers to resources nor interactions between farms (labour, field renting, livestock entrustment, gifts…).
- The Nutrient Monitoring (Nutmon) toolbox (De Jager et al. 1998; van den Bosch et al. 1998) has been adapted to the Western Niger farming system and partially tested by J. Busqué (2004) and by B. Djaby (on going work). 'Nutmon' is not a simulation model but software designed to assess and monitor nutrient fluxes and economic indicators at the farm scale. The toolbox is part of a more general approach of participative agricultural development, in which monitoring of farm ecology and economy is a tool to guide on-farm trials and management decisions. Nutmon provides a well-structured framework that enforces systematic recording of variables on primary and secondary production units, storing and redistribution units, labour and market flows at farm scale and at monthly intervals (Fig 5). The toolbox also contains a few simulation routines to assess flows, which are difficult to document by interviews, measure or monitor in the field, such as nutrient inputs and outputs by rain, dust, denitrification, volatilisation and soil erosion. Nutmon calculates nutrient flows and balances both at plot and farm scale and on a yearly basis. When several farms are monitored, their nutrient balances and economic performances can be compared (Busqué 2002). However, Nutmon does not provide simulation tools that can be used for ex-ante testing of the impacts of a new technology, a management or policy decision. Moreover, the structure of the farm database does not provide easy ways to assess those nutrient fluxes that are due to communal resource management. An existing multi goal-linear programming model (Hengsdijk and Kruseman, 1993, Kruseman 2000) developed to test economic and technical scenarios at farm level was adapted to the farming systems of western Niger and tested on the Fakara data base by R.La Rovere (2001). The same model had been already adapted to farming systems in the cotton belt of southern Mali (Sissoko, 1998). The model encompasses climate, soils, primary and secondary production units, as well as storing and redistribution facilities, labour and monetary flows. These components are interrelated by a web of functions, which contribute to the utility functions that are maximised by the model under criteria of production, feed security, income generation and also soil fertility maintenance. The model thus allows the test of technologies, management decisions and policies under these criteria, alone or combined, for selected farm types and scenarios. However, the simulation of the biological processes of production and nutrient flows remains very coarse. Despite additional iteration

facilities that allow assessing trends at medium term (La Rovere 2002), the approach is essentially static. Designed as a farm approach, the initial model does not provide routines to deal with communal management of resources such as grazing and forestry. Moreover, the relations between farms, and more generally farmers' response to exogenous and endogenous changes are not internalised in this model approach.

Fig 5. Farm centred structure of the Nutmon database with main primary and secondary production, farm homestead storage facilities, and household compartments. External input and output flows are identified (a) as well as internal flows (b). Charts are from the Nutman manual (van den Bosch et al. 1998).



6. Preliminary results

6.1. The farming systems of Fakara have been characterised and farm types defined by a statistical analysis of the 532 farm data base (Table13a). Five farm types were empirically defined by the homestead location (in villages, thus close to permanent water points or in camps away from permanent water points). Further groupings were based on farm endowments in productive capital in term of land to crop (relative to unit adult equivalent in the household), livestock managed (tropical livestock units per adult equivalent), available farm labour and equipment (cart, plough, animal traction) (Table13bc).

Table 13. Number and characteristics of five farm types empirically identified in Fakara canton, western Niger: a) household composition, b) cropping activities, c) livestock husbandry.

a) Household composition per farm type

Farm Type (endowed refer to farm assets)	Farm No	Dwellin g location	Household composition				
			Total No of Indiv.	Femal e	Child-ren	Labor[1]	Consu -mer[2]
Village Poorly endowed	213	Village	8.8	4.6	4.2	4.9	5.8
Village Richly endowed	126	Village	8.3	3.7	4.2	4.5	5.3
Village Mixed farmers	27	Village	15.6	7.4	8.7	8.4	9.8
Camp Poorly endowed	92	Camp	9.6	4.3	4.3	5.8	6.8
Camp Richly endowed	74	Camp	9.6	4.2	4.4	5.4	6.1

[1] and [2] in number of adult equivalent

b) Cropland assets and cropping practices per farm type

Farm Type	Farm No	Area cropped		% cropland >owned	Area manured %		Fallow practice field %
		per farm	per unit [1]		hand	corralling	
VP[2]	213	9.1	1.6	61.4	25.1	11.1	63.8
VR[2]	126	21.4	4.3	59.5	25.5	8.7	65.8
VX[2]	27	25.2	2.5	56.9	14.2	25.9	59.9
CP[2]	92	8.7	1.3	3.5	0.2	72.2	27.6
CR[2]	74	12.7	2.3	9.7	0.2	80.7	19.1

[1] per unit consumer in adult equivalent

[2] VP - Village poorly endowed; VR - Village richly endowed; VX - Village mixed farmers; CP - Camp poorly endowed; CR - Camp richly endowed

c) Livestock assets per farm type

Farm Type	Farm No	Livestock (TLU)		TLU per person[1]	Livestock (head)			donkeys (head)
		managed	owned		Cattle	Sheep	Goats	
VP	213	0.95	0.91	0.17	1.1	1.4	1.0	0.17
VR	126	0.80	0.74	0.15	0.7	1.0	1.1	0.21
VX	27	11.81	9.78	1.12	12.7	4.1	5.1	0.78
CP	92	12.52	4.59	0.60	4.5	11.9	4.6	1.48
CR	74	20.36	15.38	2.52	15.4	22.5	13.1	1.96

[1] per unit consumer in adult equivalent

About a third of the farms are camp farms, with dispersed mobile huts (although people are sedentary). These camp farms are managed mostly by Fulani and the minority of Kel Tamashek people. However some Jerma in living isolated hamlets also manage camp farms. Two third of the farms are village farms managed mostly by Jerma ethnic group. Only the village households have primary rights on the land for cropping explaining for the largest land area managed by the village rich farms (Table 13b). The camp households have access to land by contracting them from village households and do manage areas of cropland about as large as village farmers (excluding the village rich farmers).

Table 14. Cluster means and significance levels for non-hierarchical cluster solutions with two clusters in camp farms and three in village farms obtained in separate runs, or all together, by discriminant analyses of quantitative indicators of farm productive assets.

Farm assets	Village clusters			Camp clusters		F-ratio		Probability	
	1 (118)	2 (159)	3 (90)	1 (50)	2 (75)	Village (367)	Camp (125)	Village (367)	Camp (125)
Crop land per adult	1.03	2.22	1.75	0.92	0.97	35.10	2.12	<.0001	0.1481
Livestock per adult	0.13	0.10	0.69	2.72	3.98	63.69	53.70	<.0001	<.0001
Consumers[1]	5.16	7.62	10.91	6.66	9.49	42.24	30.22	<.0001	<.0001
Farm assets	All farm clusters					F-ratio		Probability	
	1 (118)	2 (160)	3 (90)	4 (49)	5 (75)				
Crop land per adult	1.03	2.20	1.76	0.55	1.19	28.80		<.0001	
Livestock per adult	0.62	0.14	0.87	2.93	3.23	62.28		<.0001	
Consumers	5.14	7.71	9.28	6.60	10.86	3.22		<.0001	

[1] Number of consumers per household expressed in adult equivalent.

From their pastoral culture, the camp households have inherited higher livestock husbandry skills (especially regarding long distance seasonal transhumance), and are in general better endowed in livestock than village people (Table 14). They have easier access to manure for the crop fields and practice. Village farmers raise livestock but in more limited numbers with the exception of a small group of farmers. This small group of farmers with a large area of land and quite a number of livestock has a significantly high household size and forms about 10% of the village farms (Table3b). Clustering methods have been used to analyse selected farm descriptors of the farm database, separately for village and camp farms in order to validate farm types defined empirically. There is a good correspondence in the criteria to classify farms between the cluster and empirical classifications (Table 15). However the boundaries of the classes differ and as a consequence many farms shift from one class to the next . These shifts are due in part to different source of information used for the crop land endowment of the farm, which was more precise in the cluster approach and the exclusion of 5 off-layers farms in the cluster approach.

Table 15. Contingency table of the farm clusters[a].

Empirical farm types	Village clusters			Camp clusters		Total
	1	2	3	1	2	
Village Poorly endowed	84	41	11	-	-	136
Village Richly endowed	22	118	45	-	-	185
Village mixed farmers	0	3	20	-	-	23
Camp Poorly endowed	-	-	-	58	9	67
Camp Richly endowed	-	-	-	33	46	79
Total clusters	106	162	76	91	55	490

[a] Analysis based on the whole farm data set (492 farms) with the clusters obtained by separate analysis of the village farm and the camp farm data sets. Contingency coefficient = 0.41 and 0.39, with Chi-Square 30.98 and 61.93 for camp and village farms respectively.

Farm types were also compared to farmer's own perception of farm types and wealth ranking. Within each of the two communities (village and camp farms), 3 to 5 farm types were identified based on wealth expressed in crop yields, livestock capital, farm assets and family holdings (radio, beds, bicycles).

Table 16. Number of farms classified in wealth categories defined by the farmers themselves, and criteria (mean values) suggested by farmers as defining these wealth categories in Fakara.

	Wealth groups	Number of farms	Millet yield (bundles)	Cowpea (kg grains)	Food stock (months)	Cattle No	Sheep & Goats No
Village farms	High	29	895	10	25	38	52
	Medium	103	389	4	11	7	14
	Low	142	102	2	7	2	4
	Very low	113	32	-	2	0	6
Camp farms	High	41	750	14	19	77	123
	Medium	45	350	7	10	29	42
	Low	48	83	2	5	5	7
	Very low	32	26	-	2	1	2

Natural resource management practices and alternative off-farm activities were also used to identify farm types. Farmers identified more wealth levels than farm types identified from the database. The characterisation of the two extreme wealth classes, ‘high’ and ‘very low’ by the farmers were very extreme, somehow a caricature. (Table 16).

- The data on family composition recorded in 1994 and again in 1996 were analysed (Kimba, 2001). The overall population density of 30 inhabitants km^{-2} (21 in TigoTégui, 29 in Banizoumbou and 42.9 km^{-2} in kodey). The previous published national population census (1988) counted 2113 inhabitants in the three main villages of the study area while the population in 1996 was 2710 (Table 17). The annual rate of increase is close to the overall rate calculated for Niger rural population in 1998, which is characterised by one of the highest rate of fecundity of women (7.5 children per woman). As expected, the distribution of the population in age classes is sharply unbalanced with close to 60% of the population below 20 years of age (Table18).

Table 17. Human population of the three main villages of the study zone in 1988 (national census) and in 1996.

Villages	1988 census					1996 survey	
	Male	Female	Total	Households No	Indiv. /house -hold	Total	Annual rate of increase
Banizoumbou	544	510	965	106	9.10	1224	3.0
Kodey	266	292	558	76	7.34	678	2.5
Tigo Tégui	298	292	590	75	7.87	808	4.0
Total	1019	1094	2113	257	8.10	2710	3.2

- Statistics on population density, rate of increase, composition and activities. Seasonal transhumance of the herds to the north during the rainy and cropping season, toward the Dallol Bosso early at harvest season and later on in surrounding village lands later in the dry season, explains the seasonal variability of herders presence in the Fakara. Seasonal exodus and emigration is a major issue in this rural society.

Photo 3

Meeting with Farmers in Kodey, Fakara, 2002.

Table 18. Distribution of human population (1996) in Fakara according to age classes.

Age classes	Male (52,3 %)		Female (47,7 %)		Total	
	N	(%)	N	(%)	N	(%)
0-4	364	7,32	360	7,24	727	14,56
5-9	419	8,43	408	8,12	827	16,63
10-14	370	7,44	321	6,45	691	13,90
15-19	352	7,08	336	6,76	688	13,83
20-24	232	4,65	208	4,18	440	8,85
25-29	181	3,64	165	3,32	346	6,96
30-34	127	2,55	167	3,36	294	5,91
35-39	98	1,97	136	2,73	234	4,71
40-44	98	1,63	92	1,85	191	3,84
45-49	81	1,71	59	1,19	140	2,82
50-54	85	3,27	48	0,97	133	2,67
55-59	73	1,47	22	0,44	95	1,91
60-64	49	0,99	23	0,46	72	1,45
65-69	24	0,48	10	0,20	34	0,68
70-74	16	0,32	8	0,16	24	0,48
75-79	13	0,26	6	0,12	19	0,38
80 et +	16	0,32	5	0,10	21	0,42
Total	2598	------------	2374	---------	4973	100,00

6.2. Resource assessment: soil types and maps.

- Soil types. Except for the organic matter content which is more linked to management, the main soil characteristics can be related to land form and topographic position (Table 19, Fig. 3) . Thus, the depth of the loose soil above either weathered sandstone or iron pan, the texture and colour of the loose material are major characteristics of the soil types. The texture of the top soil also determines, together with the land use, the types and proportions of different soil surface features as defined by Casenave and Valentin (1992). With these a correspondence matrix can be established between soil types and the probability of occurrence of the different soil surface features, including surface crusts, under different management scenarios (Table 20). In turn, the proportions of the different types of surface features influence the hydrological properties of the soils and the redistribution of rainfall water in the landscape.

Table 19. Soils types and main characteristics.

	Arenic Gleysol	Gleyic Arenosol	Leptic lixisol	Arenic Cambisol	Arenic lixisol	Ferralic arenosol	Skeletic leptosol
Topography	Valley	valley	down-slope	flats	mid-slope	up-slope	plateau
Land form	river bed	alluvial deposit	erosion surface	colluvial fan	sand deposit	eroded deposit	plateau cliff
Depth (cm)	> 300	> 300	20 to 80	> 300	> 300	10 to 50	0 to 10
Color (0-20)	10YR5/6	5YR 5/8	7.5YR3/4	10YR6/4	7.5YR4/6	5YR5/6	7.5YR 5/6
Texture at 0-30 cm depth							
gravels (% total)	0	0	0	0 to 5	0	0 to 20	20 to 90
Sand coarse%	2-5	45-48	40-50	45-50	40-50	34-36	32-35
Sand fine%	35-40	40-45	35-40	38-42	40-50	50-53	32-38
silt %	30-35	2-3	5-8	3-5	2-3	4-7	5-8
clay %	15-25	6-12	7-12	5-10	2-5	4-8	12-17
pH (water)	5.5-6.3	5.0-5.3	5.0-5.5	4.5- 5.5	5.2-6.2	5.0-5.9	5.0-6.0
CEC (meq/100g)	5.0-7.0	1.5-2.0	2.0-2.5	1.0-2.0	0.8-1.2	1-1.6	2.0-2.5
Total N (ppm)	250-350	60-120	150-200	200-250	100-250	150-250	200-300
Total P (ppm)	2.5-5.0	1.5-2.0	1.2-2.5	1.5-2.0	1.5-3.5	0.7-1.5	2.5-5.5
K (meq/100g)	0.20-0.40	0.02-0.03	0.02-0.03	0.03-0.05	0.03-0.06	0.04-0.09	0.20-0.30
OM (%)	0.40-0.80	0.08-0.25	0.25-0.35	0.20-0.70	0.12-0.17	0.15-0.30	0.1-0.5

Sources: Desconnet, 1994; Gavaud and Boulet, 1967; Rockstöm and Valentin, 1996; Tropsoil, 1991

6.3. The soil agronomic aptitudes .The soil types defined on the base of topography, land form and top soil texture are grouped by level of agronomic aptitude (Fig. 6). For this purpose, the soil types have been ranked along soil chemical fertility gradient considering CEC, pH and organic matter content, and soil infiltration gradient considering depth, topographical position, texture and crusting. This empirical ranking allowed the grouping of soil types into five categories of soil aptitude:

- The loamy sands and clayed loams in colluvial and alluvial depression (Tv, Rv, Vv), which constitute the 'rich' soil group. These soils offer the highest potential for cropping, but these soils are susceptible to flood because of their down position, which can destroy crop. Besides, the relatively fine texture of the soils renders them more difficult to till.
- The thick sandy soils moderately leached (Pd, Td, Rd, Vr, Vd). They constitute the 'fair' soil group. These soils are very easy to till and offer a fair potential to crop millet and cowpea provided either manure inputs or regular fallowing is applied.

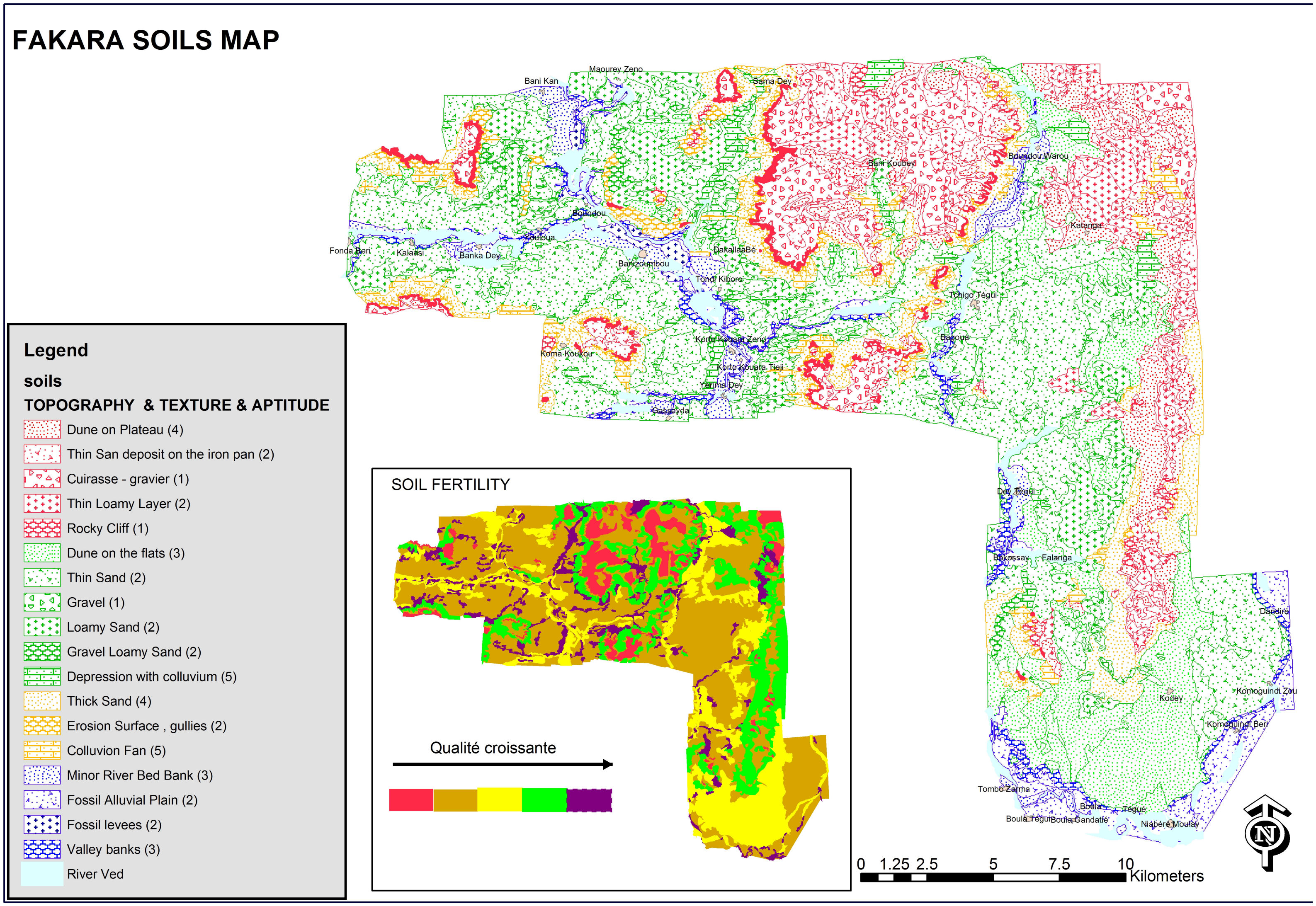
- The thick sandy soils highly leached (Rd, Vr, Vd) constitute the 'poor' soil group. These soils are very easy to till but offer a poor potential for cropping because of the inherent poor fertility of their very sandy material.
- The shallow sandy and loamy sand soils, and the highly leached alluvial sandy soils (Pl, Rl, Tr; Rr, Pe, Re, Ve). These are 'marginal' soil group. These soils offer a marginal cropping potential and they are very susceptible to erosion.
- The indurated and rocky soils (Pg, Pr), which constitute the 'null' soil group. These soils are normally not arable.

Table 20. Area covered by the different forms of surface features in uncropped lands with the different soil types.

Soil Types	Soils surface features (Valentin and Bresson, 1992)						Run-off ratio %	Water retention		Infilt. mm h^{-1}
	BIO	DR1	ST3	SED	ERO	GRA		pF 2.5	pF 4.2	
Skeletic leptosols	22	2	13	7	20	26	52	-	-	8-70
Ferralic arenosols			45		50	5	85	3-4	1.6-2.0	5-120
Arenic lixisols		77	5		18		30	2-3	1.3-1.6	300-600
Arenic cambisol	10	40	20	25	5		25	3.5-4.5	2.5-3.0	300-600
Leptic lixisol		5	20		40	35	60	4-6	2-3	5-120
Gleyic arenosol	5	80	10	3	2		20	2-3	1.2-1.5	300-600
Arenic gleysols	10		5	70	15		0	-	-	8-30

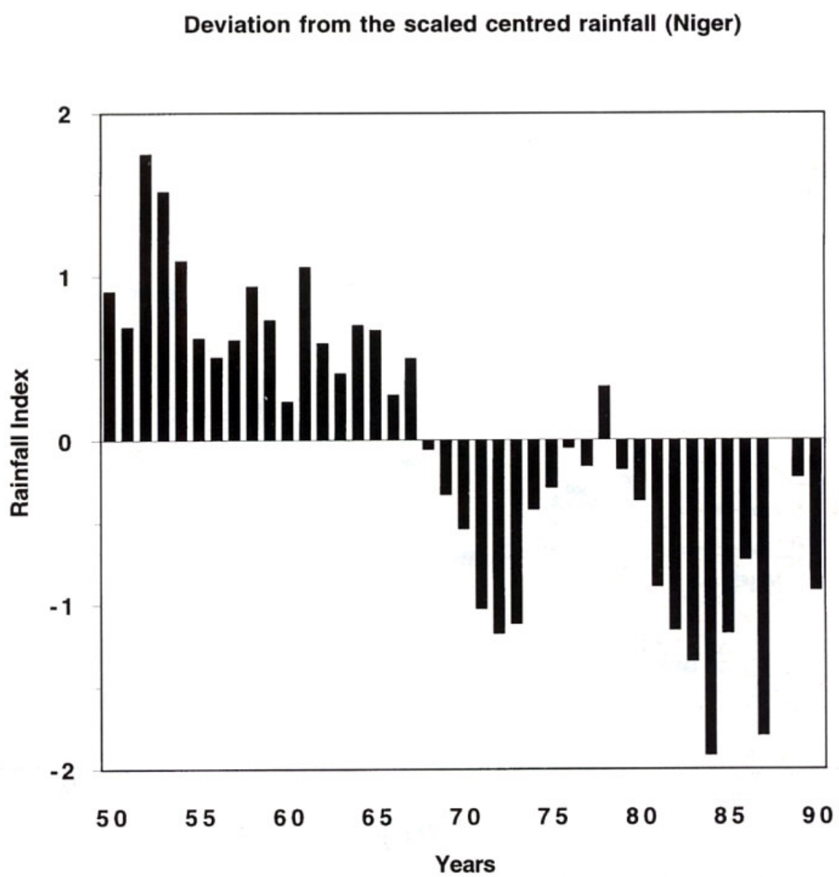
Sources: adapted from: d'Herbes and Valentin, 1997; Hammer, 1994;Valentin and Bresson, 1992

Figure 6. Map of the topographic, geomorphic, and soil texture units of Fakara study sites in Western Niger. Derived map of soil potential aptitude for cropping (fertility gradient).



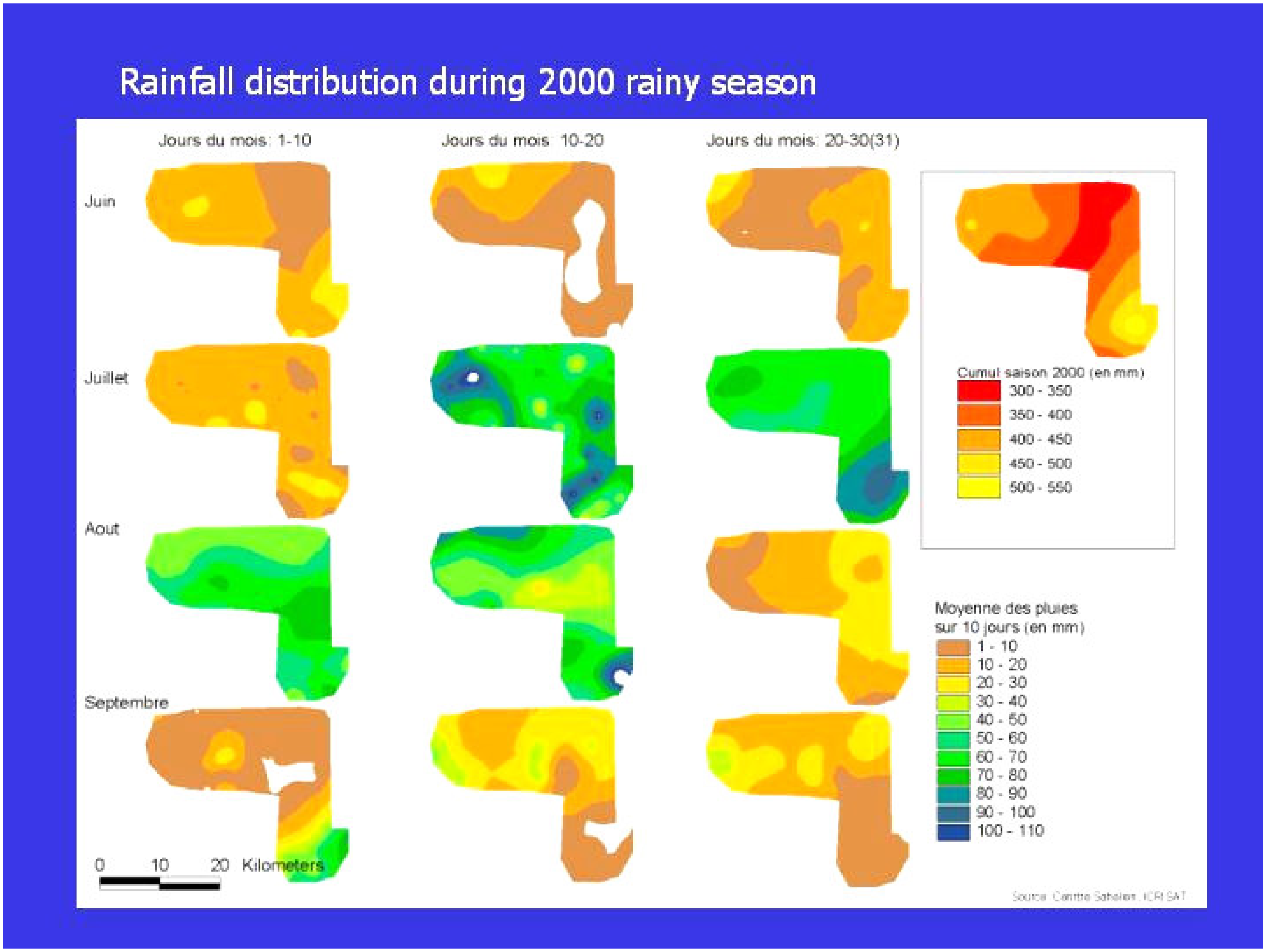
6.4. Like for all West Africa, the rainfall regime of Fakara is regulated by the West African monsoon system. Annual rainfall varies largely around the mean, with standard deviation of 22% for Niamey between 1950 and 1989 (Le Barbé and Lebel, 1987). These inter-annual fluctuations are not random over time. They define series of wet and dry years as indicated by the changes of rainfall index (square root of the mean square difference of annual rainfall to period mean) calculated for 1950-1990 data of 20 rain gauges in Niger (Fig. 7). Till 1967 annual rainfall was higher than average, then two dryer periods followed with just one wet year in between: 1968-1977, 1979-1987. From 1994 till 2003 the annual rainfall returned to above average. The two dry periods in the 60's to 80's were not the first drought observed in history. There were similar droughts earlier in the 20th century and in more ancient times according to the farmers oral tradition (Beauvilain1987, Bonfiglioli 1989).

Figure 7. Variation of the rainfall index (see text) for Niger from 1950 to 1990.



At regional scale, annual rainfall varies with the main direction of the monsoon system. Means over extended periods defining isohyets follow approximately the latitudes (Fig 2). Annual pattern however are less regular and are affected by the meso-scale variation in rain distribution. At local scale, (a few km to a few tenth of km) annual rainfall is variable as it is from year to year (Fig. 8). Over-years, no regular pattern has been found of the patchiness of annual rainfall (Lebel et al. 1997). The spatial and temporal distributions of rainfall within a rainy season are also very patchy and variable. The study of their distribution demonstrated however that the distribution of previous rains in the season tended to influence that of successive rains: rains tend to be more frequent and higher over areas that had earlier rains. This then probably explains the large difference (but not consistent over years) in total annual rains at a short distance as observed in the Fakara.

Figure 8. Spatial distribution of rainfall over the Fakara study site by decades and for the whole wet season 2000.



(Source B. Gérard, ICRISAT)

6.5. The expansion of areas cropped since mid 20th century in Fakara followed the increase of the rural population with a annual rate of growth of 3.3% (Table 21). Savannas, with no sign of previous cropping, covered 44 to 77% of the site lands in 1950. By 1975, this had almost disappeared in Kodey, the most densely populated site in the study area. Between 1975 and 1992, savannas had disappeared in the other two other. The area of rangelands, which corresponds to uncultivable lands remained stable, while total cropped areas (area of field intensively cropped with manure) increased. The fallow and thickets, either old fallows or bush encroachment in rangelands that benefited from run-on, first increased rapidly till 1975 but decreased slowly thereafter.

Table 21. Land use changes from 1950 to 1995 in three sites named by the main village (Banizoumbou, TigoTégui, Kodey) in Fakara, western Niger.

Site	year	Relative area (%)							
		Pristine savanna	Crop extensive	Crop intensive	Total Crop	Fallow	Rangeland	Thicket	Built areas
Bani	1950	76.5	3.6	0.4	4.1	5.1	14.3	0.0	0.0
Tigo		73.1	2.6	0.1	2.8	8.2	15.9	0.0	0.0
Kodey		44.1	20.4	1.0	21.4	25.5	9.0	0.0	0.0
Bani	1975	25.3	18.1	2.2	20.3	37.8	16.4	0.0	0.1
Tigo		21.1	11.3	2.2	13.5	48.7	16.7	0.0	0.0
Kodey		0.8	32.6	5.4	38.0	53.8	7.3	0.0	0.0
Bani	1992	0.0	21.0	2.4	23.3	54.0	12.3	10.2	0.1
Tigo		0.0	26.0	5.4	31.3	46.5	16.2	5.9	0.1
Kodey		0.0	49.4	5.1	54.4	36.5	4.7	4.3	0.1
Bani	1994	0.0	20.2	6.6	26.8	41.3	17.2	14.6	0.1
Tigo		0.0	31.4	8.8	40.2	32.9	14.7	12.2	0.1
Kodey		0.0	54.2	9.7	63.9	24.4	5.6	6.1	0.1
Bani	1995	0.0	17.3	6.3	23.6	41.5	16.5	18.2	0.2
Tigo		0.0	27.8	8.9	36.7	35.3	14.5	13.5	0.1
Kodey		0.0	52.2	13.9	66.1	23.5	5.0	5.4	0.1

- The historical change in land use does not result from gradual and linear expansion of lands cleared for cropping as suggested by the charts in Fig. 9. Because of large area fallowed and the shortening of the fallow duration with increasing pressure on the land, land use changes between consecutive years affected 45% and 30% of the study site area between 1994-1995 and 1995-1996, respectively (Fig. 10). The rate of land use change that applies locally and the landscape fragmentation that accompanied these changes are thus much higher than district, regional or national statistics point out. Farmers in Fakara have historically relied on long fallow periods (over 15 to 30 years depending on inherent soil fertility) for soil fertility regeneration (Loireau, 1998). Fallow practices have, however, changed in response to increased pressure on arable land. Surveys conducted in the nearby district of Hamdallaye, a region still loosely settled, showed that fallow periods last for 2-3 years on borrowed lands, and 3-5 years on farmer-owned lands instead of the previous practice of long fallow (Taylor-Powell et al., 1991). The monitoring of 63 sites in Fakara from 1994 to 2003 confirmed the trends but distinguished three different practices. First, there are increasing areas of fields under permanent cropping which require fertiliser inputs, mainly as manure (table 1), to be sustainable. Second, short cycle fallow with an average of 3.0 (±0.3) years of fallow alternating with 4.9 (±0.3) years of cropping. Third decreasing areas of long term fallowing with same 4.9 years of cropping alternating with 14.4(±2.9) years of fallow. The area of field intensively cropped increased over time since 1950 (Table 21).

Figure 9. Land use changes from 1950 to 1992 in the study site in Fakara, western Niger

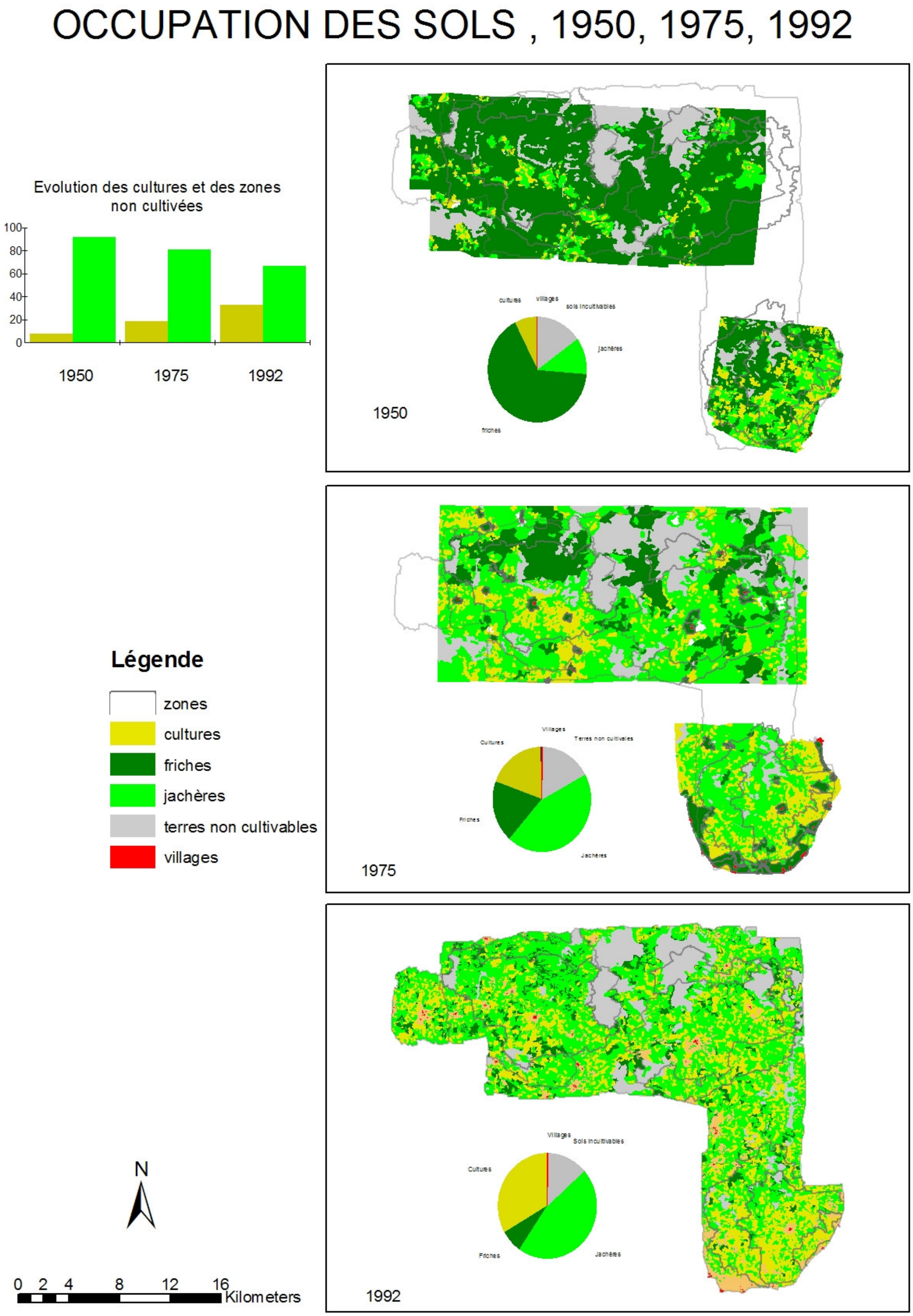
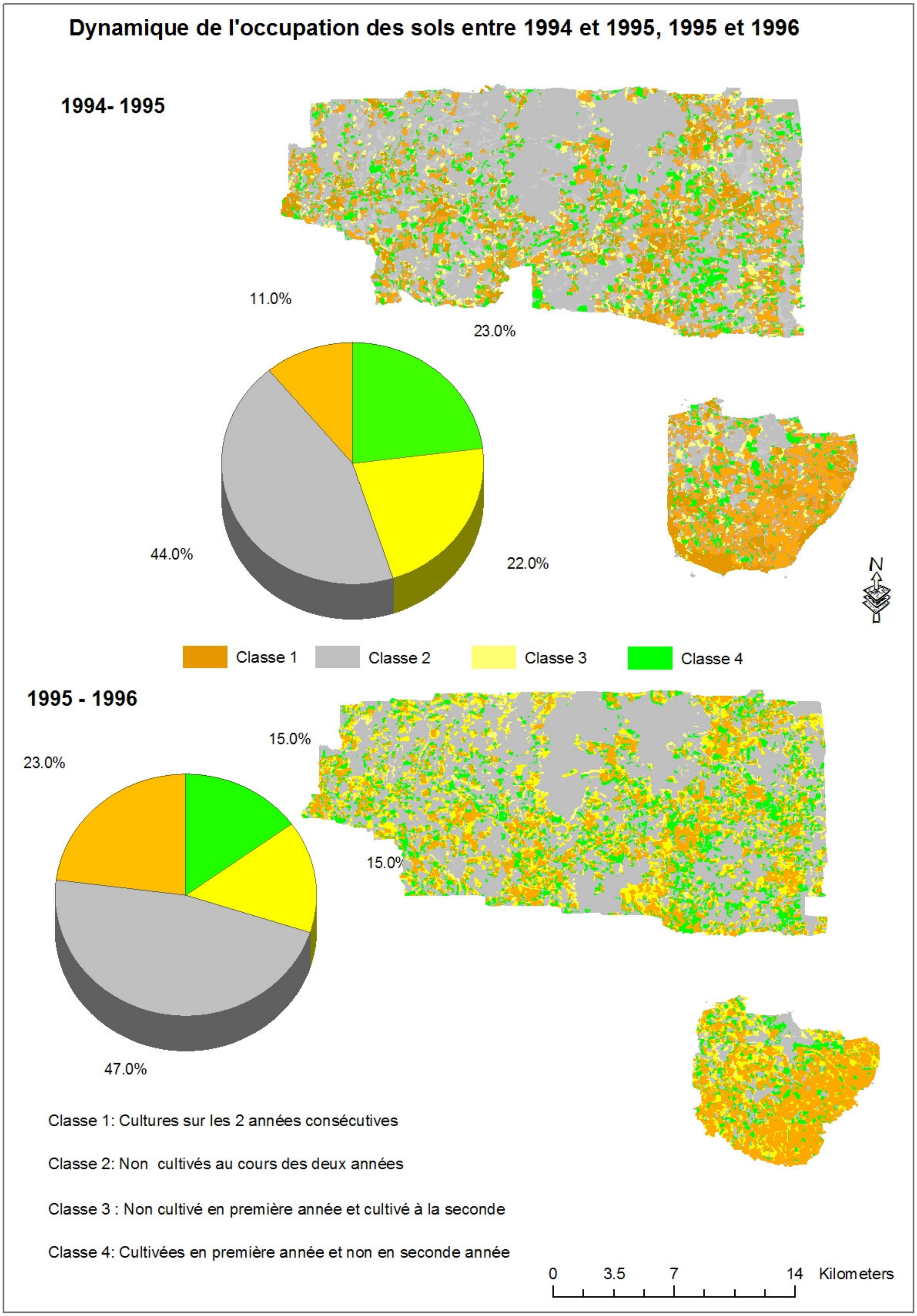


Figure 10. Changes in land use between consecutive years 1994-1995 and 1995-1996 in study sites in Fakara, western Niger.



This increase has been driven by increasing rural population density from 3% in Banizoumbou to 8% in Kodey in 1998 (Table 20). Despite the increase, only 1% or less of the cropped area (about 5% of the area permanently cropped) are effectively manured by corralling on a particular year (Table 22), based on year-round monitoring of corralling practices and farm survey on manual application of manure and fertiliser. However, the rate of manure applied by corralling is quite high (12.7 ±4.9 for cattle, 6.8 ±4.5 for sheep and goats). Thus a residual effect of the amendment is expected over 4 to 5 years. Manual application of manure transported from barn or paddocks and house wastes increased the area amended by 1 to 3%.

Table 22. Characteristics of the corralling systems depending on animal species and site.

	Bani	Tigo	Kodey
Number of corral spots (y^{-1})	1054	1198	992
Aggregated year corral area (ha y^{-1})	143	280	112
Aggregated year corral area (% cropland)	0.5	0.4	1.1
Area manually manured (% cropland)	1.1	2.9	2.5
Total area regularly manured [1] (% cropland)	3.6	4.9	8.0
Total feces excreted (t DM y^{-1})	833	803	690
Feces deposited away from corral-barn (t DM y^{-1})	474	464	399
Feces deposited in corral-barn (t DM y^{-1})	359	339	291
Feces in corral-barn/total excreted %	43	42	42

[1] Five times the annual corralled spots area plus the area manually manured every year.

Table 23. Sustainability of the cropland management for each farm type of the study sites (Banizoumbou (B), Kodey (K) and Tigo (T)), in Western Niger.

Site	Farm type	No	Land cropped not manured	Land cropped manured	Arable land fallowed	Manured over total cropped	Index of unsustainability of crop soil fertility
		#	Ha $farm^{-1}$	ha $farm^{-1}$	ha $farm^{-1}$	%	%
B	CP	29	5.1	3.6	12.1	42.4	49.2
	CR	9	9.3	2.7	12.0	23.5	75.9
	VX	12	12.7	4.3	31.8	18.9	54.4
	VP	118	9.2	1.7	19.7	17.7	52.1
	VR	28	8.3	1.3	16.6	14.0	57.5
T	CP	30	3.7	1.7	7.8	35.3	44.6
	CR	26	2.2	2.2	16.0	53.0	40.6
	VX	11	22.5	6.6	30.5	26.1	66.8
	VP	85	10.5	1.9	16.3	17.7	62.2
	VR	30	9.7	2.4	13.4	19.2	75.4
K	CP	36	5.7	3.1	1.6	35.4	124.3
	CR	21	5.7	4.5	1.7	46.0	121.0
	VX	3	23.7	4.0	5.0	20.8	135.7
	VP	41	9.9	0.7	4.5	7.4	115.3
	VR	30	16.7	1.3	8.5	9.1	113.9

Farm types: CP camp poor, CR camp rich, VX village mixed farmers, VP village poor, VR village rich.

[a] The sustainability of soil fertility in non manured croplands is calculated relative to the threshold of 5/8 (area required to manage the minimum duration of fallowing:3 years out of 8).

- When land use is analysed for the different farm types separately (Table 23), the contrast between farm types is higher than between sites. The village farmers having tenure rights on the land are better endowed in croplands than camp farmers. Due to their better endowment with livestock, the camp farms have a larger proportion of their fields manured (23 to 53%), representing 1.7 to 4.5 hectares. However, the area of land fallowed differs between the farms at Kodey and the farms of the other two sites. In Kodey, the pressure on the land is such that the area fallowed ranged between 1.6 -1.7 ha in camp farms and 4.5 - 8.5 ha in village farms while in the other sites it ranged between 7.8 and 31.8 ha. The area under fallow is more related to the sustainability of crop soil fertility than the area cropped.. In this sense, the farms in Kodey have degradation values above the threshold in all farm types. On the other hand, in Bani and Tigo values are always well below the degradation threshold indicating that farms at these two sites are capable of sustaining their crop soil fertility (Hiernaux and Turner, 2001).

6.6. Woody plant populations differ largely between the three main land use types. Average standing wood mass on croplands was 600 kg whereas it was 7,000 on fallows and 12,000 on rangelands. The leaf mass on croplands was 49 kg per ha on croplands versus 660 on fallows and 1056 on rangelands over the whole Fakara (Table 24) . However, the higher fraction of palatable species on croplands compensated for the contrast between land use in palatable foliage mass.

Table 24. Average leaf, palatable leaf and wood masses (DM ha^{-1}) of trees, shrubs and all woody plants in the three main land use groups of the study site in Fakara, western Niger.

Land use		Leaf mass (kg ha^{-1})			Palatable leaf mass (kg ha^{-1})	Palatable Leaf %	Wood mass (t ha^{-1})
		tree	shrub	Total			
Ranges	mean	162.7	893.5	1056.3	236.0	23.7	11.9
	s.d.	17.1	57.7	67.1	14.4	0.4	0.8
Fallows	mean	11.9	648.4	660.3	183.6	27.9	6.8
	s.d.	3.1	14.7	14.8	4.4	0.2	0.2
Cropland	mean	19.8	29.3	49.0	17.1	34.4	0.6
	s.d.	2.2	3.2	3.8	1.2	0.6	0.0

The differences between land use largely explains for the difference in woody plant resources between the three sites (Table 25). Indeed the lower density, leaf and wood masses of woody plants in Kodey could be attributed to the extend of croplands (60.9%) which is almost twice as much as in Banizoumbou.

Table 25. Density, leaf and wood mass (DM ha^{-1}) of trees, shrubs and all woody plants for the three main land use types in the study sites (Banizoumbou (B), Kodey (K) and Tchigo (T)) in Fakara, western Niger.

Site	Land Use	Area (%)	Density (#ha^{-1})			Leaf mass (kg ha^{-1})			Wood mass (t ha^{-1})		
			Tree	Shrub	Total	Tree	Shrub	Total	Tree	Shrub	Total
B	Ranges	7.6	126.5	913.2	1039.7	30.7	207.7	238.5	2.1	9.3	11.5
K		3.5	63.6	529.8	593.3	12.4	115.4	127.8	1.1	5.4	6.5
T		5.1	119.1	820.4	939.5	27.8	164.0	191.8	2.0	8.4	10.4
B	Fallows	36.9	4.0	757.9	761.9	1.2	210.8	212.0	0.1	7.7	7.8
K		27.3	13.9	410.6	424.5	4.2	112.8	117.0	0.2	4.2	4.4
T		36.8	8.6	688.9	697.5	2.3	189.7	192.0	0.1	7.0	7.2
B	Cropland	34.3	11.4	23.2	34.6	5.7	6.5	12.1	0.2	0.2	0.4
K		60.9	27.0	56.2	83.2	14.5	15.0	29.4	0.5	0.6	1.0
T		39.0	12.6	16.3	28.9	4.5	4.5	8.9	0.2	0.2	0.4
B	All woody plants	31.5	15.1	357.7	372.7	4.7	95.9	100.7	0.3	3.7	3.9
K		46.3	22.4	164.8	187.2	10.4	43.9	54.3	0.4	1.7	2.1
T		28.3	14.1	301.5	315.6	4.0	79.9	83.9	0.2	3.1	3.3

This overall reduction of woody plants masses and densities with increasing crop areas is however not even. The trees yields in fact slightly increased while that of shrubs decreased markedly. The spatial distribution of the woody plant population in landscape (Fig 11 and 12) is determined by both land use and soils. The shallow soils of the plateaux, which are left in rangelands, support the relatively dense population of 'brousse tigrée' type with relatively high wood and foliage masses in spite of the stripped pattern The cliff at the edge of the plateau, and the top-slope immediately in contact, often eroded by a web of gullies, are also left in rangelands but with much open woody populations contrasting with that of the plateau. At the other end of the topographic situations, the valleys may also have relatively high wood and foliage mass, or very low, depending on the cropping pattern. The density and mass of the woody population on the sandy slopes will range in between, and depend very much on the relative proportion of crop field and fallow and of the age of these fallows. The decreasing trend with increase of area cropped and shortening of the fallow duration appeared markedly when comparing the maps of wood mass, and also of leaf mass, between the three site: Banizoumbou, the less cultivated, Tigo Tégui and Kodey, the more intensively cultivated.

Figure 11. Distribution of the leaf mass of the woody plants over the Fakara study site

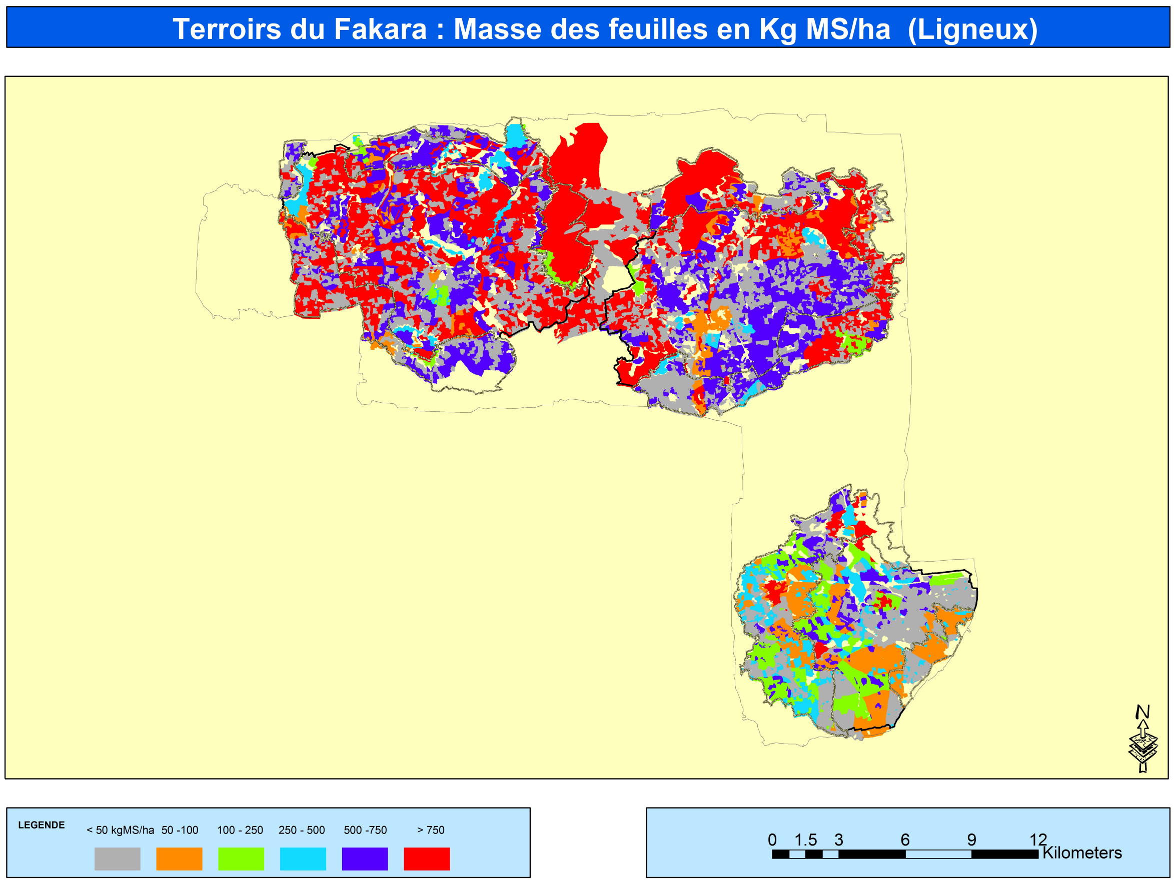


Figure 12. Distribution of the wood mass (trees and shrubs) over the Fakara study site.

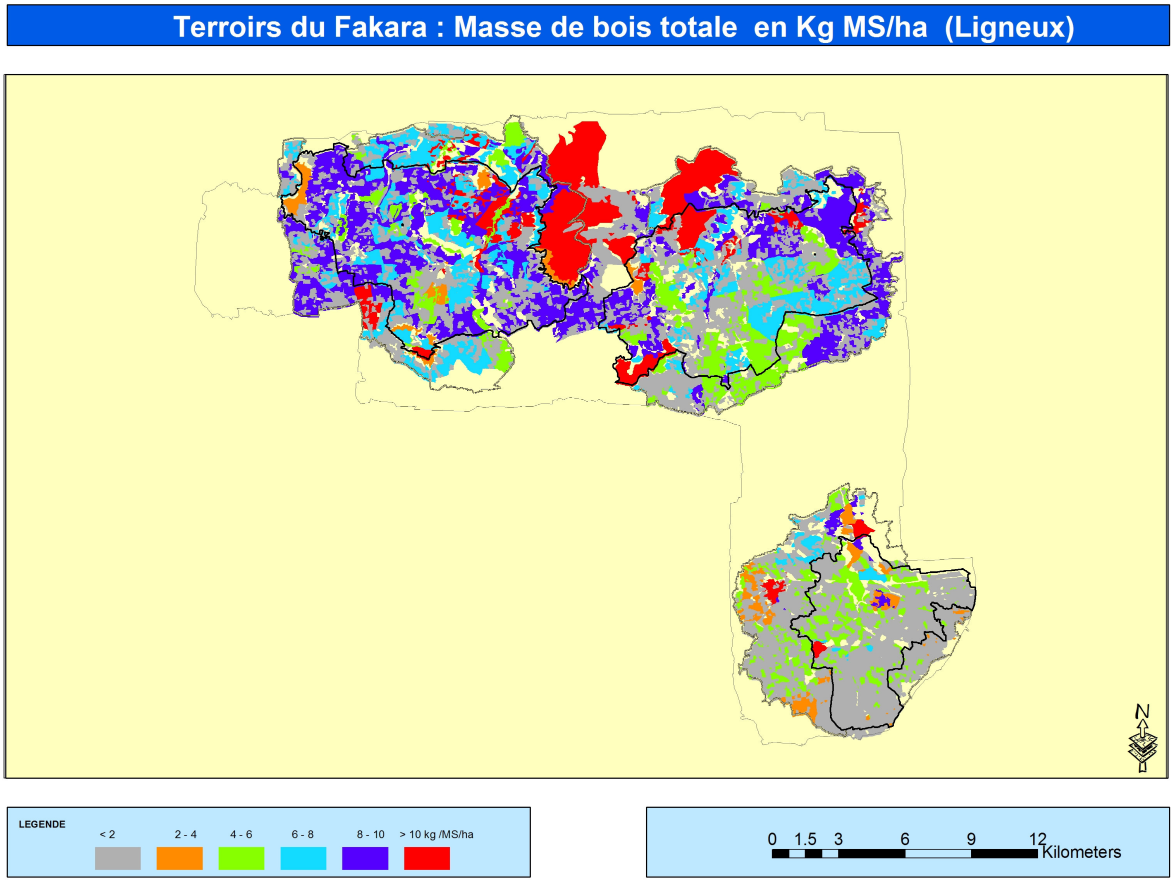


Table 26. Contribution of trees and shrub species (identified by the four first letters of genus and four first letter of species name) to the aggregate mass of woody plant leaves over the Fakara study site.

All landscape Fakara Leaf mass 4-9.2 (19.0) kg ha^{-1}							
Dominant species	Leaf mass kg ha^{-1}			Dominant species	Leaf mass kg ha^{-1}		
	Mean	s.d.	%		Mean	s.d.	%
GUIE SENE	232.3	8.8	49.5	SCLE BIRR	0.3	0.1	0.1
COMB MICR	125.3	11.1	26.7	ACAC NILO	0.2	0.1	0.0
COMB GLUT	30.8	1.6	6.6	CASS SIEB	0.2	0.1	0.0
PILI RETI	17.2	0.9	3.7	TERM AVIC	0.2	0.1	0.0
COMB NIGR	15.2	2.1	3.2	PARI MACR	0.1	0.0	0.0
AZAD INDI	4.3	1.3	0.9	PTER ERIN	0.0	0.0	0.0
ACAC ALBI	4.1	0.9	0.9	DALB SISS	0.0	0.0	0.0
ACAC ATAX	3.2	0.5	0.7	COMB ACCU	0.0	0.0	0.0
ACAC MACR	2.8	0.6	0.6	BUTY PARK	0.0	0.0	0.0
ANON SENE	2.4	0.4	0.5	HYPH THEB	0.0	0.0	0.0
BALA AEGY	1.2	0.2	0.3	EUCA CAMA	0.0	0.0	0.0
PROS AFRI	1.1	0.1	0.2	PERG TOME	0.0	0.0	0.0
DETA MICR	0.7	0.2	0.2	ZIZI MAUR	0.0	0.0	0.0
BOSC SENE	0.5	0.2	0.1	BAUH RUFE	0.0	0.0	0.0
PROS JULI	0.3	0.2	0.1	ACAC RADD	0.0	0.0	0.0
LANN ACID	0.3	0.2	0.1	VITE DONI	0.0	0.0	0.0
BOSC ANGU	0.3	0.1	0.1	ANOG LEIO	0.0	0.0	0.0

- The composition of the woody plant population is largely dominated by five species, of which four are part of the Combretaceae family. The shrub *Guiera senegalensis* alone contributed to nearly half of the woody plant foliage mass (Table 26). When land use is separated, *Guiera senegalensis* appeared to be the dominant contributor to fallows with up to 71.4 % of leaf mass (Table 27). *Guiera senegalensis* also dominates in cropland but less so compared to fallows. It is accompanied by the trees that constitute the agrarian park *Combretum glutinosum*, *Acacia albida*, *Prosopis africana*, *Detarium microcarpum*, and *Sclerocarya birrea*. In the rangeland, *Guiera senegalensis* only ranked second after *Combretum micranthum*, followed by the major components of the 'brousse tigrée' thickets *Combretum nigrican*, *Piliostigma reticulata* and *Acacia ataxacantha*. The different species composition between land use reflect in the spatial pattern of dominant species (Fig 13 and 14) which is further influenced by local edaphic differences (for example).

Table 27. Contribution of trees and shrub species (identified by the four first letters of genus and four first letters of species name) to the aggregate mass of woody plant leaves in the cropland, fallows and rangelands of the Fakara study site.

Croplands Leaf mass 49.0 (±3.8) kg ha^{-1}				Fallows Leaf mass 660.3 (±14.8) kg ha^{-1}				Rangelands Leaf mass 1056.3 (±67.1) kg ha^{-1}			
Dominant species	Leaf mass kg ha^{-1}			Dominant Species	Leaf mass kg ha^{-1}			Dominant species	Leaf mass kg ha^{-1}		
	mean	s.d.	%		mean	s.d.	%		mean	s.d.	%
GUIE SENE	20.4	2.2	41.6	GUIE SENE	471.2	11.4	71.4	COMB MICR	536.1	44.6	50.8
COMB GLUT	7.6	0.7	15.5	COMB GLUT	63.5	3.1	9.6	GUIE SENE	266.6	22.4	25.2
ACAC ALBI	5.2	0.7	10.7	COMB MICR	50.2	5.9	7.6	COMB NIGR	75.4	9.8	7.1
COMB MICR	3.1	1.2	6.2	PILI RETI	27.6	1.1	4.2	PILI RETI	32.8	3.2	3.1
PROS AFRI	1.9	0.2	3.8	ANON SENE	5.4	1.1	0.8	COMB GLUT	22.7	4.0	2.2
PILI RETI	1.6	0.2	3.3	ACAC ALBI	2.3	2.0	0.3	AZAD INDI	18.8	6.1	1.8
DETA MICR	1.5	0.3	3.1	BALA AEGY	2.2	0.5	0.3	ACAC ATAX	15.0	2.4	1.4
AZAD INDI	1.3	1.1	2.7	PROS AFRI	0.9	0.1	0.1	ACAC MACR	13.7	2.8	1.3
ANON SENE	1.0	0.2	2.1	BOSC SENE	0.7	0.3	0.1	ACAC ALBI	4.9	2.2	0.5
BALA AEGY	0.9	0.2	1.9	COMB NIGR	0.6	0.2	0.1	PROS JULI	1.7	1.1	0.2
PARI MACR	0.2	0.1	0.5	ACAC ATAX	0.5	0.5	0.1	LANN ACID	1.7	0.8	0.2
SCLE BIRR	0.2	0.0	0.5	TERM AVIC	0.3	0.3	0.0	BOSC ANGU	1.6	0.5	0.1
COMB NIGR	0.2	0.0	0.4	ACAC MACR	0.2	0.1	0.0	BOSC SENE	1.4	0.6	0.1
TERM AVIC	0.1	0.0	0.2	ACAC NILO	0.2	0.2	0.0	SCLE BIRR	0.8	0.3	0.1
BUTY PARK	0.1	0.1	0.1	DETA MICR	0.1	0.1	0.0	CASS SIEB	0.8	0.3	0.1
ACAC NILO	0.0	0.0	0.1	SCLE BIRR	0.1	0.0	0.0	ACAC NILO	0.6	0.3	0.1
HYPH THEB	0.0	0.0	0.0	CASS SIEB	0.1	0.1	0.0	PTER ERIN	0.2	0.2	0.0
EUCA CAMA	0.0	0.0	0.0	COMB ACCU	0.1	0.1	0.0	DALB SISS	0.2	0.2	0.0
PERG TOME	0.0	0.0	0.0	BOSC ANGU	0.0	0.0	0.0	BALA AEGY	0.2	0.1	0.0
BOSC SENE	0.0	0.0	0.0	PROS JULI	0.0	0.0	0.0	TERM AVIC	0.1	0.1	0.0
BOSC ANGU	0.0	0.0	0.0	BAUH RUFE	0.0	0.0	0.0	PROS AFRI	0.0	0.0	0.0
ZIZI MAUR	0.0	0.0	0.0	ZIZI MAUR	0.0	0.0	0.0	ZIZI MAUR	0.0	0.0	0.0
CASS SIEB	0.0	0.0	0.0	PARI MACR	0.0	0.0	0.0				
ACAC MACR	0.0	0.0	0.0	ACAC RADD	0.0	0.0	0.0				
ANOG LEIO	0.0	0.0	0.0	VITE DONI	0.0	0.0	0.0				
				ANOG LEIO	0.0	0.0	0.0				

Figure 13. Geographic distribution of dominant tree species in Fakara study site.

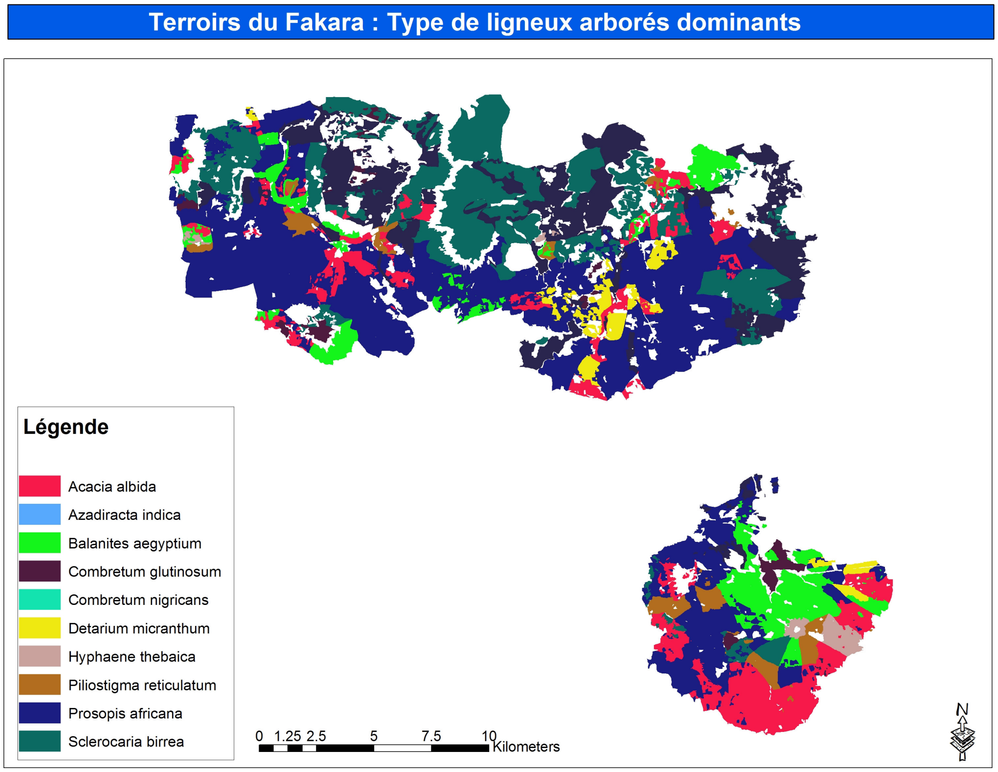
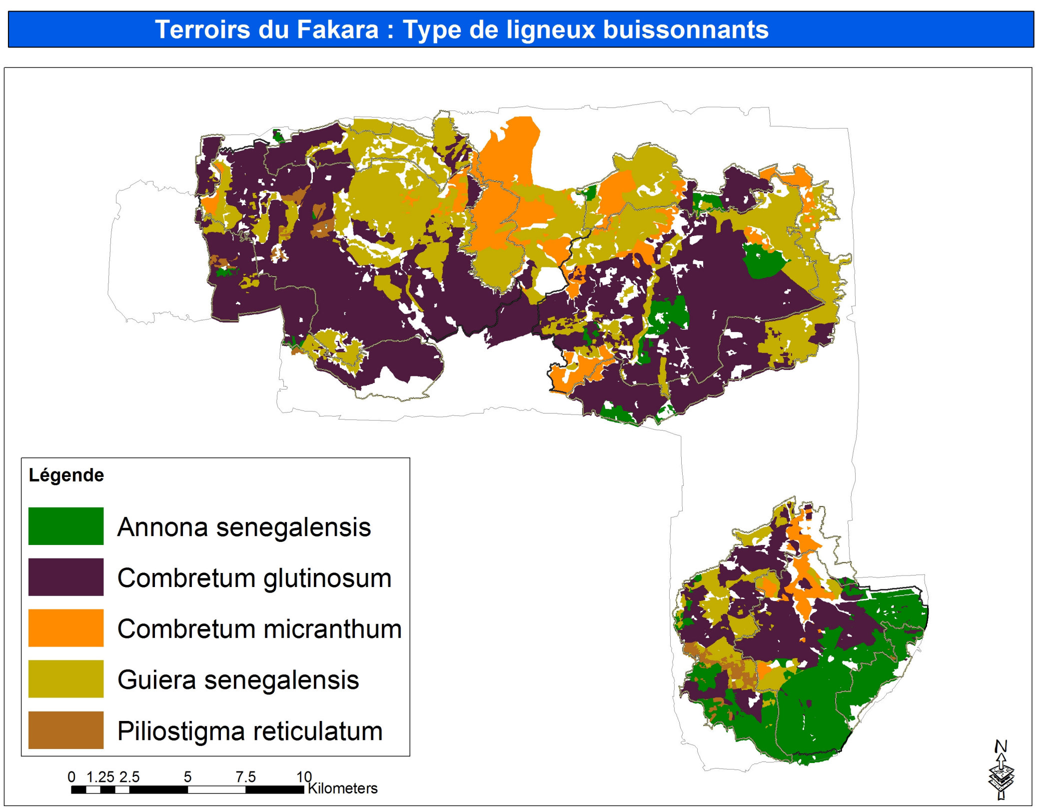


Figure 14. Geographic distribution of dominant shrub species Fakara study site.



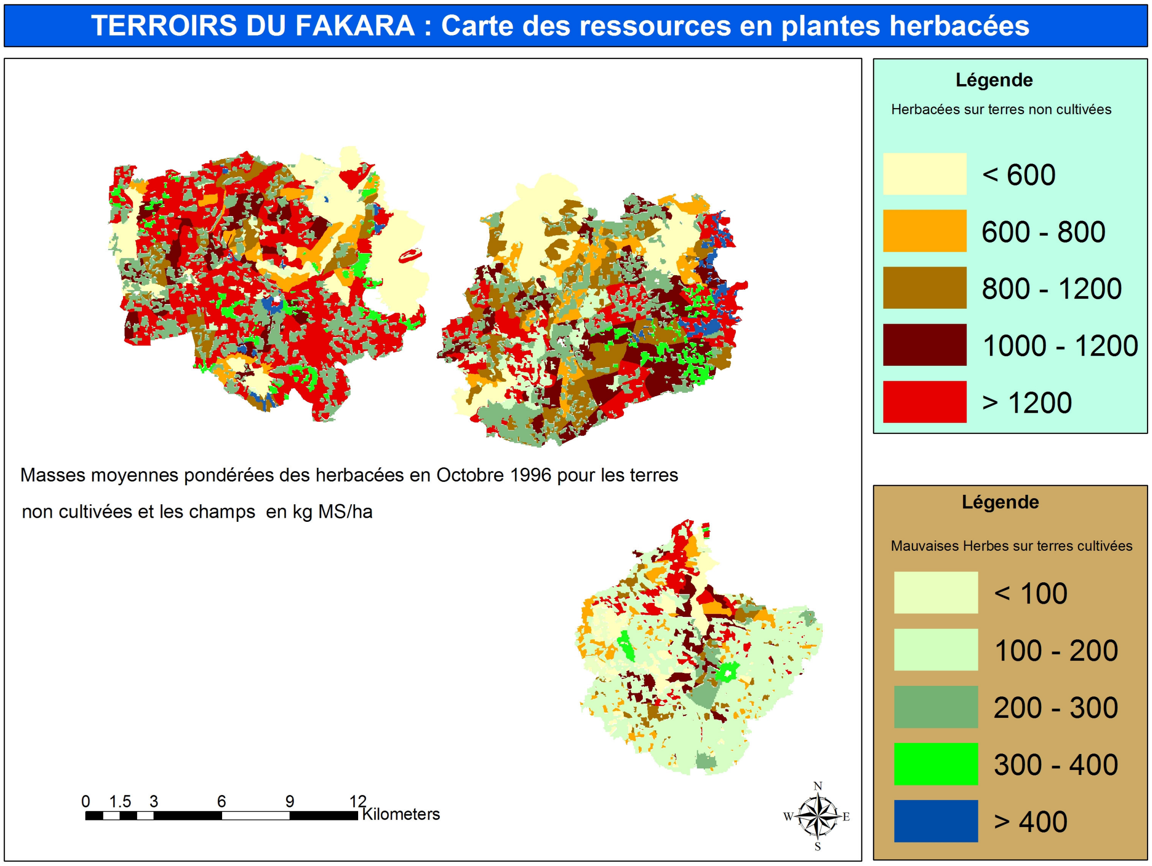
6.7. Herbaceous production in the study sites was determined from herbage mass measured at the end of the wet season in croplands, fallows and rangelands. Overall mean masses ranged between 1000 kg and 2000 kg DM ha-1 depending on year and site (Table 28). Results showed that the year 1996 was a good production year while 2000 was a poor year in all three sites. Mean herbaceous masses in fallows and rangelands are of the same order of magnitude compared to the overall means. The herbaceous in croplands include the cereal crop, mainly millet stalks that are left on the field after grain harvest, and weeds. Because of systematic weeding (once or twice during the cropping season), the mean mass of weed ranges between 50 and 200 kg DM ha^{-1}. The yields of millet stalks ranged between 700 and 2000 kg of which the leaves (blades and sheath) accounted for 400 to 900 kg ha^{-1}. Spatial distribution of herbaceous mass (Fig.15) thus highlights the contrast between fallow, rangelands (low herbaceous masses in the "brousse tigrée") and crops (low weed masses, millet stalks being assessed separately).

Table 28. Weighted (by area) average of the standing mass of the components of herbaceous communities, all together or separated by land use type, for the three study sites in Fakara (B: Banizoumbou, K: Kodey, T: TigoTegui) at the end of the wet season from 1994 to 2001.

Site	Year	Area (km^2)	Standing dry mass (kg DM ha-1) in October					
			Fallows rangelands	Weeds in croplands	Millet grains	Millet Stalks	Millet leaves	Total herbaceous
B	1994	120.6	823.8	148.0	324.2	1412.1	513.0	1072.1
K		78.5	1080.0	118.5	339.5	1475.9	533.7	1408.5
T		123.2	792.4	161.0	363.2	1556.6	555.1	1204.3
B	1995	122.2	1154.0	87.4	337.9	1602.4	728.9	1316.9
K		77.0	1512.8	91.2	330.6	1559.4	715.7	1598.6
T		112.0	1434.9	102.9	347.6	1635.7	744.4	1544.1
B	1996	119.4	1844.7	135.5	376.4	1782.6	863.6	1868.8
K		76.4	1433.4	85.7	342.3	1653.6	797.1	1621.9
T		110.9	1980.7	108.9	388.2	1825.3	888.5	1960.6
B	1997	119.7	1814.5	83.0	258.9	1232.0	618.3	1652.0
K		76.4	1632.9	86.8	255.9	1221.0	612.5	1419.8
T		108.0	1940.5	97.0	297.9	1388.3	686.3	1762.1
B	1998	120.2	2068.1	86.2	275.0	1323.2	618.7	1544.2
K		77.3	2077.4	58.2	262.5	1264.1	593.4	1499.1
T		111.4	1965.4	67.0	269.8	1291.1	605.6	1447.0
B	2000	115.9	1220.3	47.3	151.4	734.0	403.3	1076.9
K		70.5	1376.1	47.3	145.2	702.9	383.4	972.4
T		104.4	1121.7	55.2	160.1	770.1	421.6	1017.5
B	2001	115.7	1676.3	63.7	192.1	904.0	489.0	1359.6
K		75.7	1765.6	74.4	175.8	832.8	449.6	1248.3
T		102.8	1750.0	91.3	195.7	916.8	492.7	1426.7

- Because of the poor palatability of some of the herbaceous species, and of the stem in millet stalks, forage resources amounted to 45 to 65% of the total standing mass at the end of the growing season. The palatable fraction of weeds, and herbaceous from fallow and rangelands ranged from 60 to 75% while the range for millet crop residue was only 35 to 55%.(Table 29). Thus, cropland expansion did not result in a large reduction of total animal feed resources produced on the land per annum, because millet stover and weeds yield about as much forage as rangelands. The major impact of land use changes is on the seasonal availability and feed quality. Indeed livestock have no access to cropland during the cropping season during which they must rely on the fallow and rangeland resources, and /or leave the

Figure 15. Standing mass of herbaceous plants in fallows and rangelands, and of weeds in croplands at the end of the growing season 1996 in Fakara study sites, western Niger.



territory for long distance transhumance to the pastoral zones inthe north. With the increase in the fraction of land cropped, the proportion of animals sent on wet season transhumance increased from 18% in Bani to 21% in Tigo and 32% in Kodey (Table 30). At these three sites, wet season forage intake by resident herds accounted for only 4 - 9% of the peak herbage mass that was determined at the end of the wet season. The availability of herbaceous biomass remained below 200 kg DM ha^{-1} from the onset of the rains in June until the start of grass heading by mid-August. Thus, despite seasonal destocking, the average wet season grazing pressure exerted on one ton of available herbaceous forage dry matter was as high as 68 TLU d^{-1} in Bani, 80 TLU d^{-1} in Tigo and 160 TLU d^{-1} in Kodey (Hiernaux et al., 1998). These livestock densities translate to average seasonal consumption rates of 32%, 38% and 76% of the available forage.

- Monitoring of herbage masses during the course of the dry season highlight the rapid decrease in vegetation mass, first in the croplands (weeds and millet leaves) and later in the fallows and rangelands (Table 31). As a result, the average herbage and litter mass at the end of the dry season ranged between 200 and 600 kg DM ha^{-1} of which mere 100 to 250 kg was palatable although of poor quality.

Table 29. Weighted (by area) average of the palatable standing mass of the components of herbaceous communities, all together or separated by land use type, for the three study sites in Fakara (B: Banizoumbou, K: Kodey, T: TigoTegui) at the end of the wet season from 1994 to 2001.

Site	An	Standing palatable dry mass (kg DM ha-1)and % of palatable mass in October							
		Herbs in fallow and rangelands		Weeds in croplands		Millet stalks in croplands		Total herbaceous in site	
		Mass	%	Mass	%	mass	%	mass	%
B	1994	540.9	65.7	95.1	64.2	1412.1	36.3	563.6	52.6
K		664.7	61.6	81.2	68.6	1475.9	36.2	633.0	44.9
T		507.7	64.1	106.7	66.3	1556.6	35.7	576.3	47.9
B	1995	856.0	74.2	60.6	69.3	1602.4	45.5	835.8	63.5
K		1088.7	72.0	69.7	76.4	1559.4	45.9	899.8	56.3
T		1056.3	73.6	70.8	68.8	1635.7	45.5	969.6	62.8
B	1996	1259.9	68.3	89.9	66.3	1782.6	48.4	1159.3	62.0
K		976.7	68.1	54.6	63.7	1653.6	48.2	899.6	55.5
T		1337.1	67.5	67.8	62.2	1825.3	48.7	1172.7	59.8
B	1997	1285.8	70.9	57.4	69.2	1232.0	50.2	1087.4	65.8
K		1202.2	73.6	65.2	75.1	1221.0	50.2	858.4	60.5
T		1431.3	73.8	73.0	75.3	1388.3	49.4	1167.9	66.3
B	1998	1363.8	65.9	59.0	68.5	1323.2	46.8	924.0	59.8
K		1376.9	66.3	41.5	71.2	1264.1	46.9	844.5	56.3
T		1308.6	66.6	46.0	68.7	1291.1	46.9	860.3	59.5
B	2000	741.9	60.8	29.4	62.1	734.0	54.9	640.9	59.5
K		838.1	60.9	31.2	66.0	702.9	54.5	564.9	58.1
T		644.7	57.5	32.0	57.9	770.1	54.7	577.5	56.8
B	2001	1026.1	61.2	39.7	62.3	904.0	54.1	803.8	59.1
K		1073.1	60.8	50.7	68.2	832.8	54.0	727.9	58.3
T		1076.7	61.5	57.1	62.5	916.8	53.7	847.1	59.4

Table 30. The practice of wet season transhumance in three village communities in the district of Dantiandou (Western Niger) depending on the relative area cropped in 1995.

Villages	Land cropped %	Households			Livestock in transhumance during the 1995 wet season		
		Total #	Managing herd	Practicing transhumance	Cattle	Sheep	Goats
Banizoumbou	30	172	53	17	314	217	117
Tigo Tegui	36	166	57	33	731	825	521
Kodey	62	110	59	48	1338	542	923

Table 31. Weighted (by area) average of the total and palatable standing mass of the components of herbaceous communities, all together or separated by land use type, for the three study sites in Fakara (B: Banizoumbou, K: Kodey, T: TigoTegui) at the end of the wet season, mid and end of the dry season from 1994 to 1998.

Site	Year	Month	Standing and litter dry mass (kg DM ha-1)					
			Fallows Rangelands	Weeds in croplands	Millet stalks	Millet leaves	Total herbaceous	Total palatable
B	1994	Jun	432.3	2.0	799.9	152.5	580.9	242.8
K			360.4	2.0	806.4	152.7	570.1	206.3
T			284.2	2.0	829.1	156.7	678.3	169.5
B	1994	Oct	823.8	148.0	1412.1	513.0	1072.1	563.6
K			1080.0	118.5	1475.9	533.7	1408.5	633.0
T			792.4	161.0	1556.6	555.1	1204.3	576.3
B	1995	Feb	450.3	8.8	919.7	255.0	582.8	292.0
K			523.9	8.9	974.4	269.7	714.2	322.7
T			526.6	8.2	900.5	249.5	769.9	293.7
B	1995	Jun	454.5	4.3	433.1	89.9	448.7	227.5
K			508.7	4.5	459.6	95.2	487.9	218.0
T			299.1	3.6	451.4	93.5	403.2	131.9
B	1995	Oct	1154.0	87.4	1602.4	728.9	1316.9	835.8
K			1512.8	91.2	1559.4	715.7	1598.6	899.8
T			1434.9	102.9	1635.7	744.4	1544.1	969.6
B	1996	Feb	570.9	6.3	719.6	225.8	584.4	342.9
K			611.9	6.2	740.0	231.8	651.9	369.1
T			674.5	6.1	701.8	220.0	690.3	322.7
B	1996	Jun	242.1	4.7	338.4	68.3	271.3	146.6
K			194.6	4.4	349.8	70.5	250.7	119.0
T			187.7	5.1	340.2	68.8	286.9	95.4
B	1996	Oct	1844.7	135.5	1782.6	863.6	1868.8	1159.3
K			1433.4	85.7	1653.6	797.1	1621.9	899.6
T			1980.7	108.9	1825.3	888.5	1960.6	1172.7
B	1997	Oct	1814.5	83.0	1232.0	618.3	1652.0	1087.4
K			1632.9	86.8	1221.0	612.5	1419.8	858.4
T			1940.5	97.0	1388.3	686.3	1762.1	1167.9
B	1998	Feb	351.8	12.7	729.8	184.8	481.3	230.6
K			345.1	10.8	805.6	199.5	512.2	228.5
T			328.5	12.6	728.0	186.1	593.8	209.6
B	1998	Jun	349.9	12.7	732.3	185.2	479.7	229.8
K			367.2	10.7	808.9	200.0	539.0	244.8
T			331.3	12.6	732.0	186.8	603.8	212.0
B	1998	Oct	2068.1	86.2	1323.2	618.7	1544.2	924.0
K			2077.4	58.2	1264.1	593.4	1499.1	844.5
T			1965.4	67.0	1291.1	605.6	1447.0	860.3

- As for the woody plants the species composition of herbaceous layer is largely dominated by a few species. In cropland weeds, the dominant species accounted for about 75 % of plant cover (Table 32). *Mitracarpus scaber,* a poorly palatable dicotyledon dominates followed by the late germination annual grass *Eragrostis tremula*, the crawling vine *Jacquemontia tamnifolia.* The flora composition of fallow and rangelands is more diverse and dominant species only accounted for about half of the herbaceous cover (Table 33). On poorly drained sandy loams of the plateau but also heavily grazed pastures on sandy soils, a small short cycle legume, *Zornia glochidiata* dominates. *Zornia glochidiata* is followed by *Mitracarpus scaber* and *Eragrostis tremula.* These species very commonly dominate young fallows followed by three grasses that are more common on the older fallows: *Schoenefeldia gracillis*, *Cenchrus biflorus* and *Ctenium elegans*.

Table 32. Average contribution to cropland weed cover in 1996 of dominant species per site and across the Fakara

Site	Species contribution to weed cover (%) in cropland (Oct 1996)							
	acanhisp	alysoval	andrgaya	arismuta	arissieb	Cassmimo	celotrig	cencbifl
B	0.016	0.016	1.433	0.000	0.022	2.051	0.404	3.047
K	0.000	0.356	2.247	0.054	0.000	1.814	0.190	0.377
T	0.000	0.000	0.683	0.000	0.000	2.033	0.309	0.079
all	0.007	0.099	1.438	0.014	0.010	1.985	0.323	1.550
	commbeng	commfors	corctrid	cteneleg	cypeamab	Eragtrem	fimbhisp	gynagyna
B	0.093	0.059	0.208	0.204	0.337	13.205	0.082	0.134
K	0.000	0.000	0.000	0.026	0.919	25.118	0.000	0.100
T	0.109	0.000	0.367	0.132	1.083	18.131	0.000	0.000
all	0.073	0.028	0.198	0.139	0.691	17.614	0.039	0.089
	indiastr	indistro	ipomvaga	jacqtamn	mitrscab	Monecili	pennpedi	phylpent
B	0.000	0.036	0.000	13.040	33.597	0.202	1.032	0.117

K	0.000	0.000	0.000	9.939	23.686	0.934	0.366	0.000
T	0.022	0.000	0.032	13.838	30.118	0.024	0.477	0.126
all	0.006	0.017	0.009	12.460	30.098	0.342	0.709	0.090
	polyaren	polyeria	schiexil	sesbpach	setaance	Striherm		
B	0.000	0.000	0.973	0.055	0.072	7.525		
K	0.308	0.538	2.534	0.000	0.000	6.838		
T	0.000	0.000	2.842	0.000	0.000	4.640		
all	0.079	0.138	1.885	0.026	0.034	6.508		

Table 33. Average contribution to herbaceous cover of dominant species in fallows and rangelands per site and across the Fakara

Site	Species contribution to herbaceous cover (%) in fallows and rangelands								
	acanhisp	achyarge	aescnilo	alysoval	amarviri	Andrgaya	Arisadsc	arismuta	arissieb
B	0.418	0.000	0.025	0.530	0.704	0.114	1.054	0.816	1.991
K	0.019	0.000	0.000	2.943	0.251	0.084	0.213	1.961	0.381
T	0.029	0.026	0.000	0.193	0.907	0.293	0.472	1.526	1.162
all	0.212	0.007	0.012	1.035	0.648	0.156	0.686	1.294	1.365
	blepmade	boererec	borrradi	borrscab	borrstac	Bracxant	Cassmimo	celotrig	cencbifl
B	0.032	0.446	1.118	0.898	0.034	0.023	0.990	0.052	5.363
K	0.000	0.190	0.000	0.479	0.000	0.561	4.316	0.000	6.017
T	0.000	0.686	2.136	0.758	0.000	1.235	0.907	0.270	1.681
all	0.015	0.449	1.121	0.756	0.016	0.489	1.790	0.099	4.514
	cteneleg	cyanlana	dactaegy	digigaya	dihehage	Eragpilo	Eragtrem	indiastr	indibrac
B	3.970	0.021	0.017	0.331	0.000	0.073	3.249	0.000	0.000
K	1.132	0.048	0.369	0.017	0.095	0.185	9.017	0.020	0.034
T	6.896	0.000	0.046	0.023	0.070	0.233	5.217	0.164	0.000
all	4.071	0.022	0.113	0.169	0.043	0.145	5.217	0.050	0.008
	indistro	ipompest	ipomvaga	jacqtamn	kohasene	Loudtogo	Merrtrid	micrindi	mitrscab
B	3.173	0.000	0.000	1.873	0.013	0.000	0.044	0.519	6.611
K	0.779	0.000	0.000	0.488	0.000	0.000	0.034	0.582	6.231
T	1.566	0.030	0.177	2.017	0.000	0.046	0.000	0.577	7.115
all	2.139	0.008	0.049	1.570	0.006	0.013	0.029	0.550	6.655
	monecili	pandheud	panisuba	pennpedi	peribica	Polyeria	Schiexil	schograc	sesbpach
B	0.211	0.564	0.087	0.831	0.000	0.000	3.293	5.009	0.053
K	3.648	0.000	0.000	0.194	0.000	0.000	4.795	5.183	0.000
T	0.910	0.410	0.015	0.346	0.059	0.017	7.022	4.146	0.000
all	1.253	0.382	0.046	0.540	0.016	0.005	4.688	4.815	0.025
	setaance	sidacord	sporfest	tripmini	triupent	Waltindi	Zorngloc		
B	0.224	0.078	0.032	0.188	1.258	1.095	13.278		
K	0.000	0.164	0.000	0.000	0.915	0.142	8.208		
T	0.000	0.463	0.000	0.000	1.230	0.099	9.509		
all	0.107	0.205	0.015	0.090	1.165	0.586	11.368		

Figure 16. Distribution of dominant herbaceous species in fallows and rangelands as observed in October 1996 in Fakara study sites.

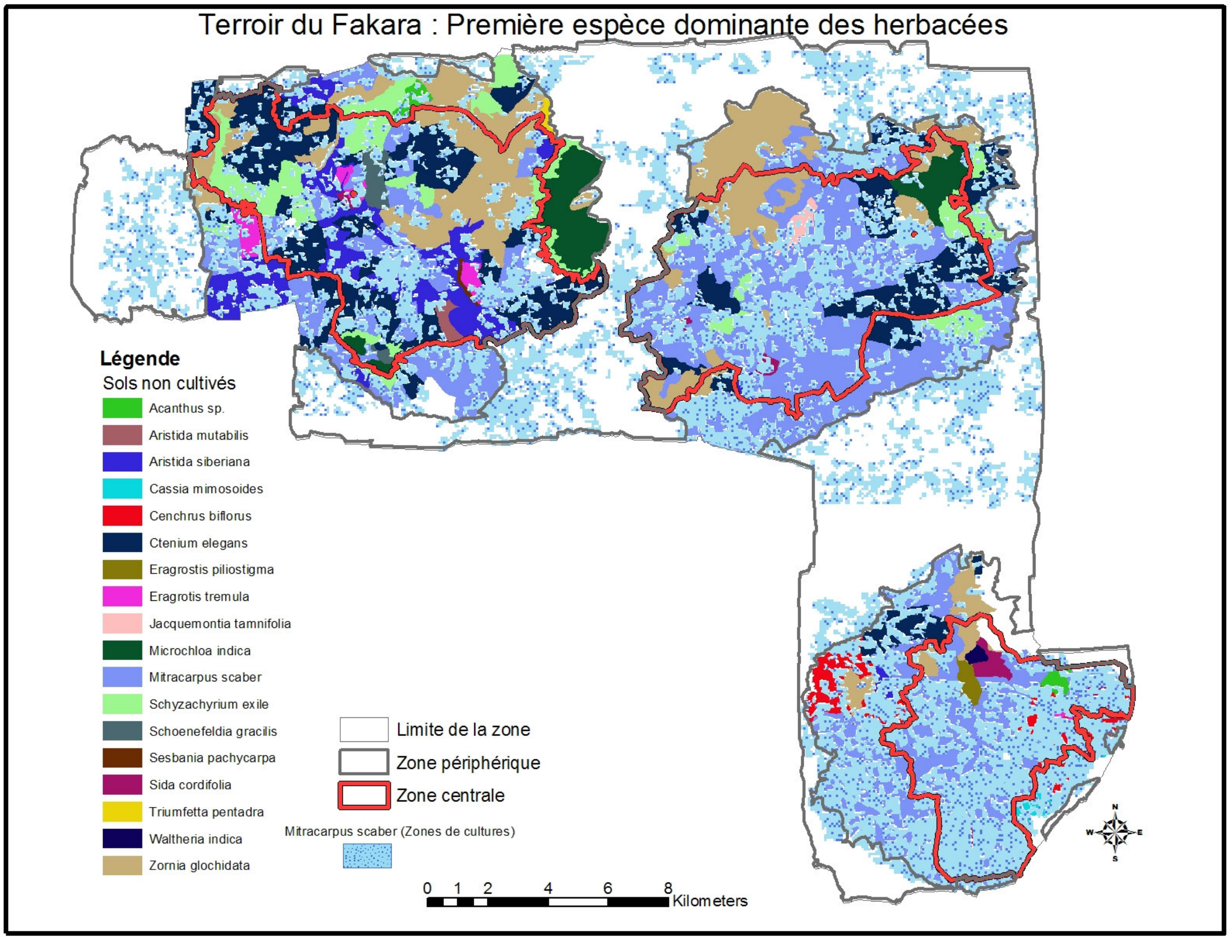


Table 34. Contribution of functional or taxonomic species groups to plant cover in cropland weeds and herbaceous in fallows and rangelands (October 1996)

Species groups	Weeds in croplands				Herbaceous in fallow-rangelands			
	Plant cover (%)		Relative contribution %		Plant cover (%)		Relative contribution %	
	mean	s.d.	mean	s.d.	Mean	s.d.	mean	s.d.
Grass	1.98	0.98	24.1	11.0	3.32	1.41	29.1	10.9
Perennial	0.27	0.45	1.5	2.9	0.40	0.59	2.5	4.0
Legume	0.38	0.52	3.1	4.0	1.11	0.75	10.4	8.2
Short cycle	0.13	0.33	0.7	2.1	0.10	0.34	0.7	2.7
Long cycle	1.61	0.89	17.1	11.4	2.73	1.46	21.9	10.0
Palatable	2.81	0.96	36.6	10.7	4.71	1.87	40.0	10.7
Zoochorous	1.16	0.56	14.6	11.22	2.76	1.34	22.9	9.5
Xerophytes	1.18	0.52	19.3	9.8	2.19	1.47	17.3	12.0
Sciaphylous	0.12	0.33	0.7	2.7	0.76	1.32	3.6	6.8
Aquatic	0.16	0.39	0.9	3.0	0.55	0.97	2.8	6.2
Plant with C4	2.05	0.96	24.7	10.5	3.39	1.34	30.4	10.3

- Species composition of weeds and herbaceous in fallows and rangelands translated also into different proportions of plant functional groups (Table 34). Grasses, C4 species, legumes, zoochorous, long cycle annuals and perennial contributed more in fallows and rangelands than in cropland weeds. As a result the proportion of palatable species is slightly higher in fallows and rangelands than in cropland weeds. Spatial distribution of dominant herbaceous species (Fig 16) highlights the dominance of *Mitracarpus scaber,* which was present every where except on the shallow soil of the plateaux. The distribution of the other species appeared more patchy, either matching with particular edaphic conditions (*Zornia glochidiata*, *Schoenefeldia gracilis* and *Sesbania pachycarpa*), or to particular pressure on land resources (*Cenchrus biflorus*, *Walteria indica*, *Sida cordifolia*), or both (*Schizachirium exile*, *Aristida sieberiana*).

Table 35. Land use (1995), households and livestock population (average number of animal present during the 5 seasons of 1995) and annual stocking rate (Tropical Livestock Unit per km ^{2}) in three sites in the district of Dantiandou in Western Niger.

Site	land area (km ^{2})	land cropped %	households		livestock			TLU /km ^{2}
			village	camp	cattle	sheep	goat	
Bani	117	34.1	169	47	789	915	560	6.6
Tigo	113	45.4	138	56	928	730	427	7.5
Kodey	76	66.5	59	63	811	740	316	9.8

6.8. Livestock population monitored over the whole study site from 1994 to 1996 and in 1998 indicated that overall the annual stocking rates increased in the three study sites, thus with the expansion of area cropped and increase density of human population (Table 35). Annual average stocking rates were 6 to 11 km $^{-2}$ for cattle, 5 to 8 for goats and 3 to 4 for sheep. Thus, cattle play a major role in the use and recycling of feed resources.

- Livestock stocking rates were systematically low during the wet season as many animals were sent away on transhumance to the northern Sahel, and high during the dry season. There was a slight increase in stocking rates during the dry season as the season progresses, reflecting the balance between local movements of animals within and away from the village territories. This wet-dry season contrast is sharper going from Banizoumbou to Tigo Tegui and Kodey. Grazing pressure also increased along the same gradient. On the rangelands, grazing pressure peaked in the wet season, dropped in the early dry and progressively increased during the dry season as it did on the croplands. The annual aggregates of feed intake by livestock only accounted for 19 to 20% of the annual herbage yields (Table 36). The spatial distribution of the grazing pressure, and the associated forage uptake and excretion deposition, depends largely on the land use but also on the location relative to water points, village, camps and cattle paths. The systematic survey of herds behavior and the monitoring of sampled herd daily itinerary were used to assess and map stocking rate at grazing and resting by cattle, sheep and goats in the whole Fakara study sites during a year cycle in 1995-1996 (Figure 17).

Figure 17. Distribution of stocking rate (cattle, sheep and goats in Tropical Livestock Unit) around the village of Bagoua and surrounding camps at resting and grazing, as influenced by land use, water point and cattle path. Example of daily itinerary for a cattle herd.

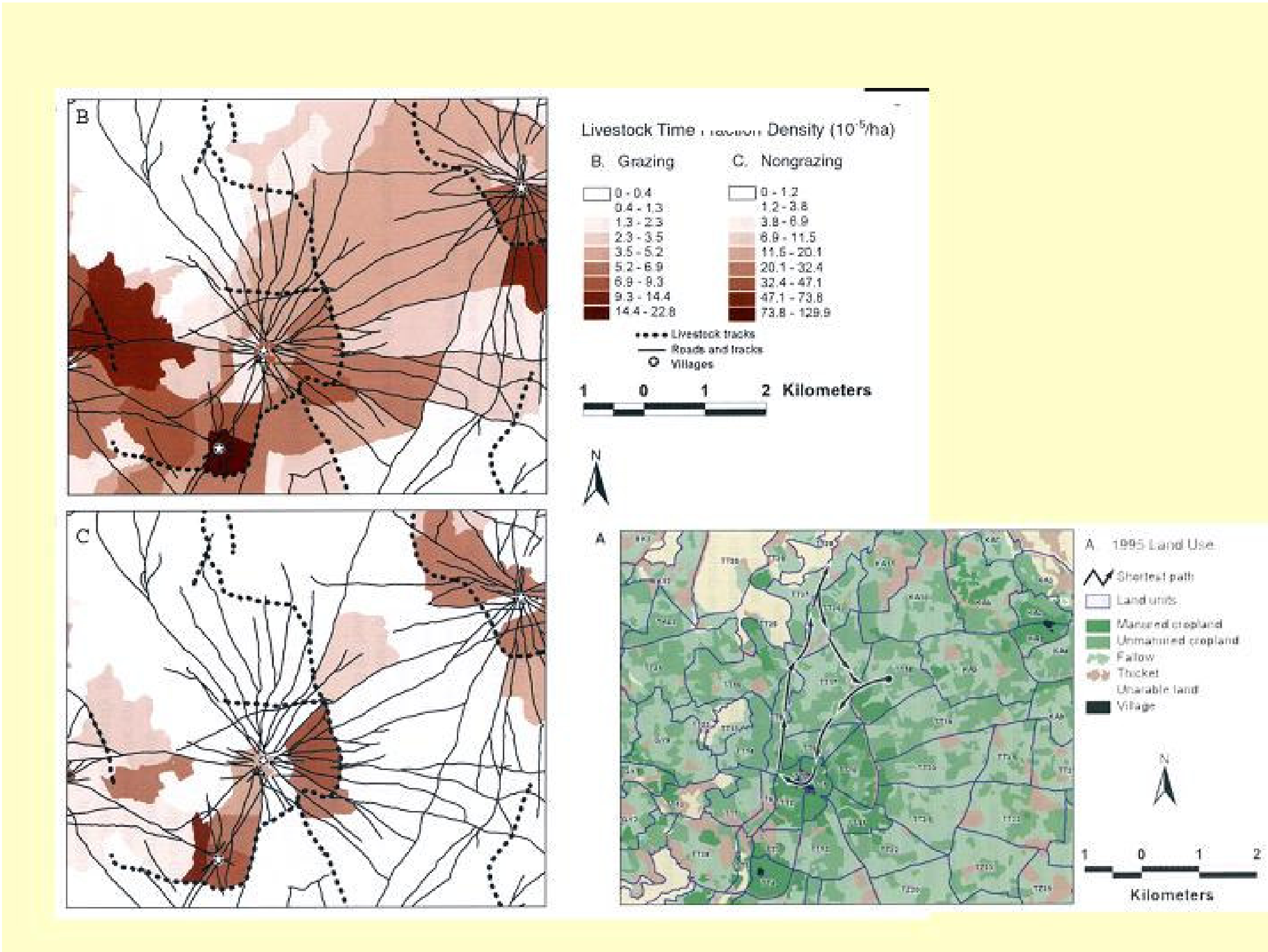


Table 36. Cattle, sheep and goat stocking rates, forage intake and faeces excreted per land use and per site.

		Bani	Tigo	Kodey
Stocking rates (TLU km^{-2})	Cattle	2.8	3.3	4.8
	Sheep	0.3	0.3	0.3
	Goats	0.3	0.4	0.6
	Total	3.4	4.0	5.8
Forage intake (kg DM ha^{-1} y^{-1})	Rangeland	1440	258	862
	Fallow	205	273	257
	Cropland	176	258	268
	Total	227	266	290
Feces excreted (kg DM y^{-1})	Rangeland	320	59	177
	Fallow	36	48	56
	Cropland	44	57	54
	Corrall, barn	969	708	507
	Total	82	83	96
Foraging efficiency:intake/offer %		19	20	20

- For all species, the herd composition is characterised by a large dominance of females (85 to 90% of the animals), with a minority of young females (25-30%) and a majority of adult females with offsprings (50-60%). Among the weaned males, close to 70% are young, that is not matured for breeding (Table 37). The proportion of adult females with offsprings differs markedly with the ownership status of the animals. It is higher for owned animals, and nil or very low for loaned animals. This is a direct consequence of the loaning arrangement ('habanaï') in which the two first born of the loaned cow became property of the manager. The calf to adult female rates of owned and loaned females put together were 65.9 ± 0.7, 64.2 ± 1.5, 66.3 ± 1.1 % for cattle, sheep and goats, respectively. These rates remain markedly superior to calf to adult female rates calculated for the entrusted and contracted animals. However, herd composition by age and physiological stage does not differ much between farm types.

Table 37. Mean herd composition ratios calculated on the basis of weighted (time between two consecutive observations) average frequency of sex and age classes per herd. The average herd ratios of calves to adult females (calves %), weaned females to total weaned animals (females %), young females to weaned females (young females %) and young males to weaned males (young males %) were calculated for cattle, sheep and goats depending on the ownership status of the animal.

Species	Ownership	n x y [1]	Calves %	Females %	Young females %	Young males %
Cattle	Owned	2077	70.0	86.5	20.0	72.4
	Entrusted	792	59.9	81.4	26.4	68.2
	Contracted	387	56.6	77.6	36.0	58.2
	Loaned	72	1.6	99.4	41.8	-
	Total	3328	59.4	86.1	26.0	69.5
Sheep	Owned	865	69.1	79.9	27.3	71.0
	Entrusted	85	53.6	89.1	34.0	53.2
	Contracted	206	47.1	85.0	28.3	67.4
	Loaned	48	0.0	99.7	43.7	-
	Total	1204	52.9	85.3	31.6	69.0
Goat	Owned	2063	71.7	85.9	24.6	70.6
	Entrusted	129	44.3	88.5	30.4	71.0
	Contracted	339	59.9	84.1	32.4	54.4
	Loaned	83	0.0	99.9	35.2	-
	Total	2614	54.1	89.0	28.3	68.9

[1] animal-year

- The frequency of birth events relative to the number of adult females varies largely between herds and this explained significant deviation of fecundity index calculated for the whole population of animals within a site and averages of fecundity indices calculated per herd (Table 38). Fecundity index is lower and more stable for cattle than small ruminants. The highest and more variable index was found in goats. No significant differences were found in fecundity index between farm types but average fecundity was high in the village of Tigo, low in Kodey for cattle and sheep and in Banizoumbou for goats. The occurrence of animal death, sales and purchase varied between species and age-physiology classes. The mortality frequency is very low with cattle compared to sheep and goats and is always higher for young males followed by unweaned or young females. Purchase and sales only applied to 'owned' animals. They are much more frequent for small ruminants than for cattle, especially young and adult males. The number of animals sold always exceeds the number purchased for all sex-age classes.

Table 38. Mean birth occurrence for hundred adult female- year calculated per herd (# number of herds) grouped per site and farm type between April 1995 and November 1996. Birth was also corrected for the birth of adult females absent from the village.

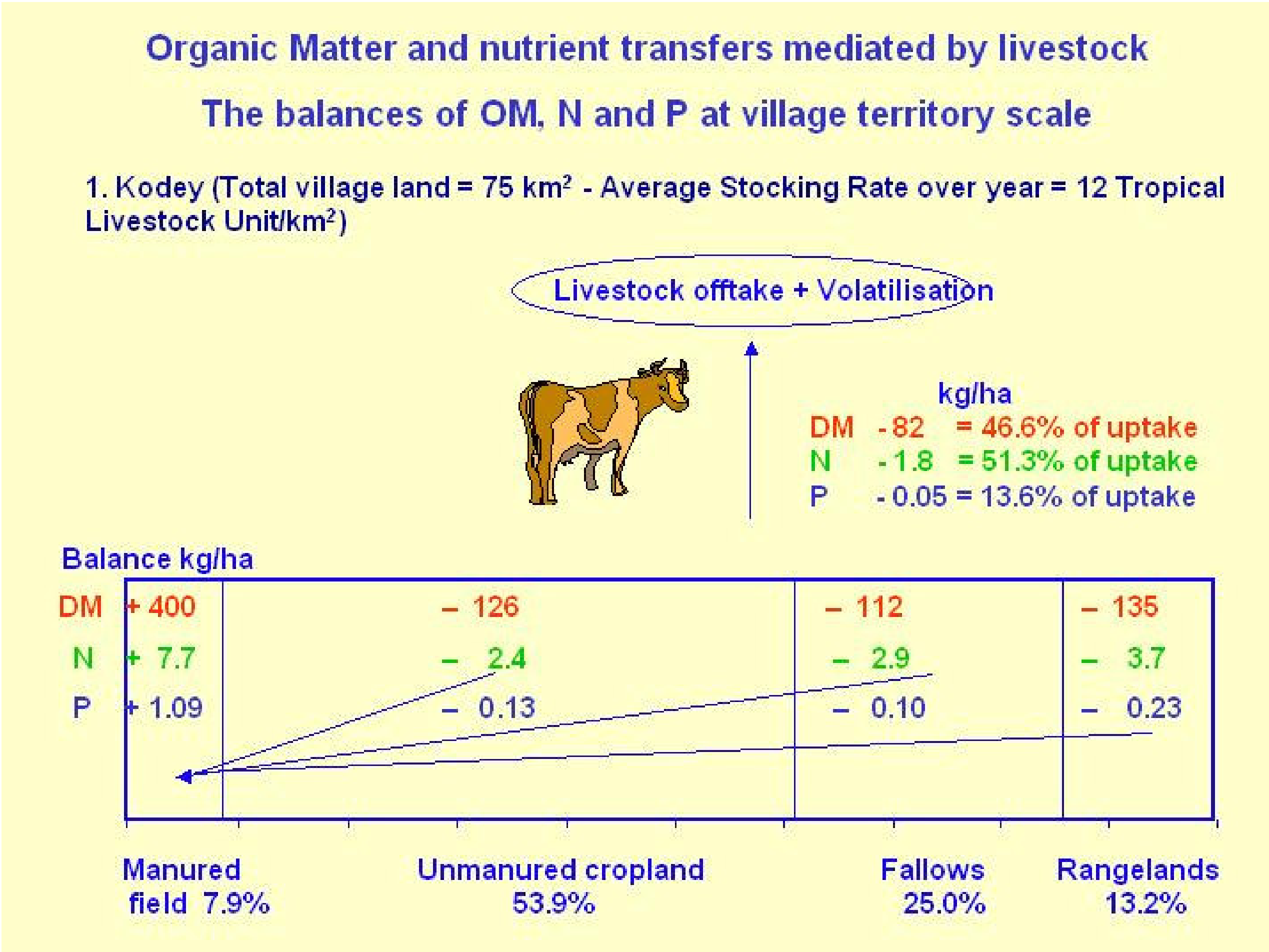
		Cattle (100)		Sheep (100)		Goat (100)	
		herd #	Calves	herd #	Calves	herd #	Calves
Farm types[1]	Camp L	58	27.3 (3.7)	32	49.4 (9.2)	50	83.6 (19.2)
	Camp H	61	29.0 (3.4)	34	69.6 (10.8)	42	59.4 (9.3)
	Village H	15	28.2 (4.7)	10	68.5 (11.6)	10	141.4 (46.6)
Farm per Site	Bani	40	32.7 (3.6)	27	57.3 (9.8)	35	52.2 (11.5)
	Tigo	51	35.0 (4.3)	33	78.8 (10.5)	38	114.4 (22.2)
	Kodey	49	16.9 (3.2)	21	42.4 (11.3)	34	78.9 (25.8)
All herds		140	27.9 (2.3)	81	62.4 (6.4)	107	82.8 (12.1)
Corrected		-	54.2	-	112.5	-	146.5

[1] Farm types: Camp L: Low asset encampment farmer; Camp H: High asset encampment farmer; village H: high asset village farmer.

Once corrected to include birth that might have occurred when the herd was away from the village, the calving rates correspond to calving intervals of 22 months for cows, 11.5 for ewes and 9.5 for does. These values are close to what was observed by Colin de Verdière (1995) and by Schlecht (2000). Death rates were also corrected, just in proportion to the time spent away from the village, while purchase and sales statistics which only concerned 'owned' animals were not corrected because it was considered that most of them might have occurred when the herds were at the village.

- Through faecal excretion, livestock recycled about 50% of the organic matter, 85% of P and 48% of N intake (Figure 18). The nutrients recycled by livestock amounted 1.2 kg N ha^{-1} of land at Bani, 1.2 at Tigo and 1.8 at Kodey, with 0.16, 0.16 and 0.24 kg P ha^{-1}, respectively. These quantities are small compared to the nutrients exported as millet grains, chaff and part of the stems, which were equal to 15.0 N kg ha^{-1} in Bani, 15.2 in Tigo and 14.7 in Kodey with 1.99, 2.00 and 1.89 kg P ha^{-1} respectively. In addition, 15.3, 17.5 and 15.4 kg N ha^{-1}, and 1.32, 1.49 and 1.20 kg P ha^{-1}, were recycled through litter decomposition. The flows and balances of organic matter, nitrogen and phosphorus resulting from feed intake and excretion by livestock were then derived from these statistics for each site as a whole or subdivided per type of land use, per season and aggregated over the year cycle (Hiernaux et al. 1997). The spatial transfer of organic matter, N and P by livestock across the agro-ecosystem is quantified in Figure 18.

Figure 18. Chart of the nutrient transfer, offtake and losses due to livestock grazing over the year in Kodey study site in Fakara.



7. Evaluated Technologies

7.1. Low productivity of ruminants in crop-livestock systems of semi-arid is mainly caused by poor nutrition. The available forage is often low and variable depending on rainfall magnitude and distribution, and soil fertility. In addition, the nutritional quality is also low especially in the dry season. The latter part of the eight-month dry season and early wet season is the most critical period for animal nutrition (Schlecht 1995). Energy and protein supplementation is often necessary during the dry season for maintenance of the animals and to reduce herd mortality. Supplementing animals during the dry season also has the added advantage of improving the fertilizer value of manure, which should result in increased crop yield (Sangaré et al. 2002). The need for supplementation is increased by night corralling of the animals on the crop fields (Ayantunde et al. 2000, 2001). Over the last decade, studies have been conducted on-station and on-farm to assess the effects of energy, protein and phosphorus supplementation on productive performance of cattle and sheep. The effects on reproductive performance have also been studied on-farm. The results (some are still preliminary) of these studies are summarized in this section.

- Sheep fattening, especially for Tabaski (annual Islamic religious festival), is an important economic activity in West Africa Sahel. Fattening is usually based on feeding crop and range residues such as millet stover, cowpea hay, groundnut hay, and cereal grain by-products (millet and wheat bran). Results from on-station experiments confirmed that the performance of fattening sheep depended on feed availability, feed types and quality. The followings were the summary of the results from the experiments:
    - Rams grazing millet residue fields soon after grain harvest had growth rates of more than 50 g/day but for a short period. After three to five weeks of grazing, low weight gain and even weight losses were observed. Intake and digestibility studies indicated that when the amount of edible material (leaf) decreased below 400 kg dry matter (DM)/ha the amount of digestible organic matter consumed decreased dramatically.
    - Studies with millet stover showed that intake of energy increased linearly as feed allowance increased up to level of 31 g DM/kg live weight. Thus, feeding fattening animals with crop residues (e.g. millet stover) in excess (i.e. allowing for a relatively high level of refusal of forage) led to increased intake of energy.
    - Higher weight gains (30-50 g/day) were recorded by supplementing sheep diet with cowpea hay than the unsupplemented diet (0-20 g/day).
    - Growth rates of more than 100 g/day were recorded from diets based upon high quality legume hays such as cowpea hay and cereal by-products such as millet bran.

- On-farm sheep fattening for Tabaski. About 40 farmers in Fakara were given loan to buy 4 rams for fattening. The sheep were fattened for about 60 days and then sold around the festival period. Feed supplements (cowpea hay and millet bran) were offered at different levels to the animals. The study was carried out for 3 years. The farmers paid back the loan after they have sold the animals. Results are shown in Tables & below. The unsupplemented sheep had a significantly lower weight gain compared to those supplemented (See Table 39).There was no significant difference in weight gains between the supplemented sheep. In terms of economic evaluation, it is profitable supplementing the animals with cowpea hay. The rate of return (%) ranged from 25 to 28% (Table 40).

Table 39. Sheep performance and feed intake at different levels of cowpea hay in the diet

	Cowpea hay in the diet (g d^{-1})				
	0	300	600	900	SE
Initial weight (kg)	29.5±2.9	35.2±6.6	35.7±5.7	35.0±4.8	-
Final weight (kg)	34.6±4.6	45.9±5.0	46.6±6.0	46.1±5.0	-
Weight gain (g d^{-1})	88.3^{b}	187.5^{a}	182.6^{a}	169.8^{a}	12.80
Intake (g d^{-1} $kg^{-0.75}$)					
- millet bran	18.63^{b}	16.63^{a}	16.33^{a}	16.35^{a}	0.61
- cowpea hay	0	13.53	25.99	36.75	1.18
- roughages	75.13^{c}	53.81^{b}	66.15^{a}	70.91^{ac}	2.40
Total intake	97.9^{a}	73.6^{b}	83.3^{a}	91.0^{a}	3.48
Intake/WG (kg kg^{-1})	28.95^{b}	6.53^{a}	8.68^{a}	8.98^{a}	3.99

Table 40. Economic evaluation of sheep fattening at different levels of cowpea hay in the diet

Prices in FCFA	Cowpea in the diet (g d^{-1})			
	0	300	600	900
Buying price	20532	19149	19778	19600
Selling price	24221	32910	34759	34061
Selling price (kg-1)	698	717	754	762
Total costs	7442	7569	7882	8159
Net benefit	-3753	6319	7099	6302
Rate of return (%)	-14	26	28	25

Despite the profitability of sheep fattening, the adoption rate has been low. The principal reason given by the farmers is lack of capital to buy rams for fattening.

- Cows supplementation. A trial was carried out in two Fakara sites from 1999 to 2002 on the effects of wet season transhumance and dry-season supplementation on cow productive and reproductive performance (Fernandez-Rivera et al. 2003). Treatments were factorial combinations of three supplement levels (0, 360 and 720 g DM millet bran per day) given at the end of dry season and two management systems (year-long sedentary management and transhumance). Results obtained from the study were:
  - Supplementation with millet bran decreased weight losses in the dry season; 1 kg millet bran per day decreased weight loss by 145±21 g/d. However, this advantage of reduced weight loss in dry season through supplementation is partially offset by lower gains during the following rainy season.
  - The effect of transhumance in term of weight change and reproductive performance of cow compared to sedentary system, was insignificant.

7.2. Soil fertility, particularly nitrogen and phosphorus have been identified as the first limiting factor of crop productivity in the Sahel (Penning de Vries and Djiteye 1982 , Pieri 1989). Cropland soil erosion is a major concern from the perspective of expansion of the area cropped and tillage intensification, in particular for Fakara (de Rouw, Rockström).

- Livestock corralling and use of manure. Over the last decade, studies have been conducted on farmers fields in Fakara and on-station at Sadoré to assess the effects of organic and inorganic amendments. The studies involved the use of mulching material, livestock manure especially by corralling animals on the field, and inputs of small amounts of inorganic fertilizers. Complementary trials were devoted to legumes, especially cowpea dual-purpose breeds, aiming at enhancing their share in their association with cereal crops. The results (some are still preliminary) of these studies are summarized in this section.
- In the trial conducted on farmers field in Fakara with manure of heifers receiving different mineral or energetic supplements 'harvested' by corralling the animals at night on fields subsequently planted with millet. The effect of supplementation was compared with direct applications of urea and/or phosphate to the soil with or without addition of millet stem litter as mulch. The experiment was carried out on two fields, one year apart (to reduce the impact of rainfall distribution on results) and the residual effects were monitored over 4 years. No additional inputs were added for the 2 first years, but the treatment for the third year residual effect was completed by the application in two bocks out of four of placed NPK fertilizer at to 2 kg P_2O_5 ha^{-1}. The objective was to test relay application of small doses of placed inorganic fertilizer after an history of organic application. No yield differences were observed with the application of N and P either through mineral supplements given to cattle corralled at night on cropped lands or through inorganic fertiliser applied directly to crops in fields manured by corralling unsupplemented cattle. The second year residual effect of 6t DM ha^{-1} manure from unsupplemented cows were still significant on grain yields with 527 ± 56 kg ha^{-1} versus 298 ± 54 kg ha^{-1} for the control. Mineral supplementation of the diet had significant effect on the quality of the manure which had similar effect on millet yield when compared to the direct application of the equivalent amount of fertilizer in the case of nitrogen (738 ± 39 versus 732 ± 78 kg ha^{-1}) and a diminished effect in case of phosphorus (634 ± 48 versus 676 ± 46 kg ha^{-1}) or of combined nitrogen and phosphorus (1225± 49 versus 672 ± 40 kg ha^{-1}).
- Another trial was conducted in farmers field in Fakara with the cow used in the transhumance- supplementation trial. The effects of manure produced by heifers fed different quantities of millet bran supplement during the late dry season were measured on subsequent millet crop. The trial was conducted using different manure rates (6, 12 and 18 t DM ha^{-1}) combined with or without inorganic fertilizer (4 kg of NPK 15-15-15). This experiment was repeated on a second field with a one-year lag, and the residual effects of the treatment were monitored for 4 years. Hill-placed phosphorus fertiliser applied at a low rate (2 g Di-Ammonium-Phosphate per hill) in addition to moderate manure application (6t DM ha^{-1}) increased millet yields yield by 350 kg grain ha^{-1} more than the sum of the yields due to each separate amendment. The application of 6t ha^{-1} of manure by corralling of un-supplemented heifers yielded 754 ± 34 versus 531 ± 91 kg grain ha^{-1} in the control. The millet yield response to the amount of manure was linear between 0 and 18 t DM ha^{-1} (Table 41).

Table 41. Residual effect of manure application (0,6,12,18 t DM kg DM ha^{-1}) during 1999 dry season (Field KA1) or during 2000 dry season (field KA2) on grain, stalks and total above ground yields of millet.

	Manure t DM ha^{-1}	Grain kg DM ha^{-1}	Stalks kg DM ha^{-1}	Total plant kg DM ha^{-1}	Grain to head %	Grain to stalks %
KA1	0	241.0	992.5	1091.5	61.0	25.0
	6	593.5	2355.2	2590.2	58.5	25.5
	12	808.7	3265.7	3591.5	58.2	25.5
	18	1068.7	4283.0	4710.3	59.4	25.0
KA2	0	330.0	992.1	1097.0	63.6	35.3
	6	604.2	1937.7	2142.7	60.0	32.3
	12	707.9	3353.3	3708.0	59.1	26.5
	18	828.8	3156.0	3489.8	58.8	27.2

- However, supplementation with different quantities of millet bran had little effects on grains although they increased stalks yields. Residual effects on grain yields were still strong three years after manuring and linearly oriented with rate of manure application (Table 42). Effect of cattle supplementation with millet bran on millet response to manure was not significant, while complementary mineral fertilisation with placed NPK was still systematically increasing yields three years after application in the case of field KA1.

Table 42. Residual effect of 6t of cow manure deposited by corralling during the dry season 1999 (KA1) or 2000(KA2), with or without combined application of 6g NPK 15-15-15 per hill, on the grain and stover yield of millet cropped for the third or second consecutive year in 2001.

Field	Manure treatment	Grain yield (kg DM ha^{-1})		Stover yield (kg DM ha^{-1})	
		No fertilizer	NPK 6 g $hill^{-1}$	No fertilizer	NPK 6 g $hill^{-1}$
KA1	No manure	278.1	166.8	1187.5	602.5
	6t; no suppl.	561.0	647.8	2105.6	2377.1
	6t, 360 g d^{-1}	537.7	608.5	2240.3	2608.3
	6t, 720 g d^{-1}	583.8	687.7	2341.7	2710.6
KA2	No manure	330.0	624.2	992.1	2071.9
	6t; no suppl.	439.3	562.9	1383.7	1838.8
	6t, 360 g d^{-1}	739.0	721.5	2302.4	2161.3
	6t, 720 g d^{-1}	624.2	548.3	2071.9	1923.3

- The effects of alternative bedding material at the corral spot were measured in a farmer field. The treatment combined the use of alternative livestock bedding: 2t DM millet stalks, 2t DM of branches of *Guiera senegalensis* and no bedding, to three corralling duration (equivalent to 6, 12 and 18 t DM ha^{-1}). Yields in the year after corralling and the two following years responded linearly to the rate of manure application. The use of Guiera bedding increased yields by 141 kg ha^{-1} grain and 341 kg stalks while a millet stalks bedding increased yields by 74 kg ha^{-1} grain and 113 kg stalks.

The results of the on-station corralling experiment allowed establishing the response curve of millet yield with the rate of manure application. The yields of millet cropped the first year were approximately linear with the rate of manure application, grain yields ranging from 700 to 2100 kg ha^{-1} for 0 to 14 t ha^{-1} of manure. Manure of small ruminants resulted in slightly higher yields than cattle manure at all rates of application. The residual effects of manure applied 2, 3 and 4 years ahead were significant and proportionate to the amount of manure applied (Table 43). When yields are aggregated over 4 years, the yield difference compared to the control reached 281∀12 kg of grain ha^{-1} and 670∀32 kg stalks ha^{-1} per tonne of manure applied in the first year, in addition to the control yield. Aggregate incremental yields over four years were not different for rates of manure application ranging from 4 to 14 t DM ha^{-1}. However, the lower rate of 2t DM ha^{-1} yielded significantly more (Table 44).

Table 43. Millet yields in manure experiment (Sadoré, Niger), all treatment means of grains, harvested stalks and total above ground mass of millet calculated for each year and plot aggregates.

Field	Year	n	Grains (kg DM ha^{-1})		harvested stalks (kg DM ha^{-1})		total millet mass (kg ha^{-1})	
			Mean	stderr	mean	stderr	Mean	stderr
5A	97	170	634.0	18.5	1772.1	72.8	3407.4	106.0
	98	170	409.2	21.8	718.2	33.7	1254.5	59.5
	99	170	681.2	19.6	1843.1	48.7	3216.4	84.2
	00	170	406.3	13.9	1042.6	29.5	1799.8	50.5
	Mean		533.4	14.4	1345.4	37.7	2421.3	62.9
1B	98	170	1400.7	40.4	2959.2	112.7	4894.7	170.2
	99	170	921.2	23.4	2559.1	66.3	480.5	110.2
	00	170	462.9	20.2	1134.4	43.9	1994.4	76.2
	01	171	364.1	15.4	1053.4	2.5	1765.6	70.4
	Mean		787.0	21.5	1920.0	57.1	3272.6	92.5
Total mean			660.6	14.6	1633.5	37.6	2848.2	60.5

Table 44. Relative millet grain yields in manuring experiment (Sadoré, Niger), yield difference (kg DM ha^{-1} per tone of manured applied) to the un-manured control (crop residues returned) in the first years and the aggregate for the first four years years after manuring depending on rates of manure application from 2 to 14 t DM ha^{-1}.

Field	Manure T DM ha^{-1}	First year		First two years		First three years		First four years	
		mean	stderr	mean	stderr	mean	stderr	mean	Stderr
5A	2	174	17	209	22	298	28	370.7	35.3
+	4	125	8	169	11	229	14	264.6	17.3
1B	6	104	7	145	9	207	11	239.2	13.4
	10	95	10	126	15	184	16	213.5	19.5
	14	71	9	145	20	209	29	240.2	29.8
	All rates	126	6	168	8	237	10	281.2	12.4

- Another corralling experiment was carried out on station at Sadoré to assess the respective contributions of urine and faeces to the fertilization effect of night corralling by either cattle or sheep-goats. The assessment was carried out with male animals fitted with faecal collection bags in order to separate faeces from urine. The separate application of urine and faeces indicated a 2 to 6 times larger response to urine than to faeces deposited by cattle and small ruminant corralled at night (ILRI 2002).

7.3. Use of inorganic fertiliser alone or in combination with manure. During the last decade, trials have been carried out in farmer's fields in Fakara by agronomists from different institutions including IRD, INRAN, University of Hohenheim, IFDC and ICRISAT. The trial results confirmed the strong limitation of crop yield by phosphorus availability and secondarily by nitrogen availability in the soil and the synergetic effect of combined organic and inorganic manure application. Trials also demonstrated that placed application of small doses of P, or P and N fertilisers such as 60 kg ha^{-1} were significant on yields and increase the efficiency of nutrient use by the plant.

- In addition to these on-farm trials, during the last two rainy season, 120 (2000) and 140 (2001) demonstration trials were carried out in collaboration with the FAO Projet Intrants on hill placed application of mineral fertilizer (NPK 15-15-15 or DAP) at a rate of 4 kg P ha^{-1} (9 kg P_2O_5 ha^{-1}) in fields with different history of organic amendments have been performed. The objective of these demonstration trials was to evaluate *in-situ,* the agronomical and economical performance of hill placed application of different formulation of mineral fertilizer associated or not to organic amendments. In order to gain more information on the interaction between organic and inorganic fertilizer, a stratification was made on previous land use. Approximately one third of the demonstration was conducted on fields which did not receive manure, one third on fields which received transported manure and one third on fields which received manure through corralling. In 2002, four strata were used to split the corralled fields into two strata according to the time of corralling: corralled in dry season 2000-2001 or corralled in dry season 1999-2000. Yields showed an increase with the application of mineral fertilizer for both years under all combinations of mineral and organic fertilizer (Table 45). The analysis of variance indicated no significant differences in grain yield ($p < 0.01$) between the application of DAP and NPK. There are, as expected, large yield differences across organic fertilization strata. Overall, grain yields were much lower than the national average for millet yields due to the unfavorable rainy season and the soil characteristic. The economical analysis of the fertilizer demonstration trials in 2001 rainy season showed on average a negative or very small return of NPK 15-15-15 fertilizer in all cases (all manure classes and millet price of 100 and 150 CFA/kg) due to the fact that the cost per fertilizer unit of 15-15-15 is 2.6 times the one of DAP.

Table 45**.** Grain yield from Fakara demonstrations in 2000 and 2001.

	Grain yield (kg ha-1)			
	DAP	DAP + Urea	NPK	Control
		Rainy season 2000		
No manure	275	na	250	157
Transported manure	375	na	370	236
Corralling in 2000	613	na	507	440
		Rainy season 2001		
No manure	173	213	180	119
Transported manure	303	318	292	258
Corralling in2000	300	325	324	261
Corralling in 2001	394	415	378	350

- In separate on-farm trials carried out at Banizoumbou from 1999 to 2001, ways to maintain or increase millet productivity in millet-cowpea intercropping systems were tested by ICRISAT. These trials entailed implementing an annual rotation between the millet and cowpea rows so as to make the millet crop benefit from the residual effects of the inputs applied to the cowpea rows in the previous year. Over the three years, there was a significant response of millet grain yield to hill-placed fertilizer application ($P<0.01$). Millet grain yield was increased by 150% following fertilizer application in 2001, which was intermediate between 1999 (210% yield increase) and 2000 (60% yield increase). The impact of fertilizer was therefore strongest on the vegetative development of millet (tillering), but also had impact on the grain forming and filling stages. There was no effect of fertilization on cowpea grain or fodder yields.

(photo P hiernaux)

9.1. Photo 2 Local zebu cattle grazing in a fallow in Tiguo Tegui, Fakara, western Niger

8. Modelling agro-ecosystems
    8.1. The bio-economic model developed by Bruno Barbier was successfully adapted to Fakara village databases (Barbier, 1998). The results highlighted the importance of seasonal transhumance as a risk management strategy as well as the importance of seasonal human emigration and off-farm income in village economy (Hezell and Barbier, 2002). However, little is known of the influence of transhumance on reproductive cattle productivity. Hence, a trial was carried out to assess this influence. As livestock transhumance is commonly practiced in Niger to help match feed availability with demand, on-farm experiments were conducted to combine wet season transhumance with late dry season supplementation in order to assess the trade-offs of these technologies on cattle performance, especially reproduction which is vital to extensive livestock production systems.

    8.2. The Fakara farm database was successfully adapted to the structure of the 'Nutmon' tool box (Busqué, 2002) and soil nutrient balances were performed for N, P and K through the assessment of the following nutrient flows: grazing forage uptake, excreta deposition during grazing time, corralling and manual manure application, and harvest of crop products. At this stage, atmospheric deposition, nitrogen fixation, N and K leaching, erosion and human excreta were not considered. Input data to the model consisted of size, type and number of livestock herds grazing in the area, spatial distribution of vegetation types, biomass and fields, and a gross indication of the different grazing routes used along a whole year. A simple mathematical model estimated the amount grazed of different forage feeds by each individual herd in individual fields for each month of a year. Forage feeds refer to different land use types (cropland, fallow and rangeland), crops (millet, cowpea and sorghum); plant groups (herbaceous and ligneous) and plant components (edible standing, edible litter, browse material). Selection among the feeds on offer in each grazing route was simulated as a function of aerial biomass availability, palatability, nitrogen concentration and digestibility of the feeds, overall grazing pressure and livestock browsing predisposition (Figures 19 and 20). Excreta deposition was simulated in considering the amount of faeces as the product of forage ingestion by its digestibility. The nutrient content of faeces was assumed as the average values per season from experiments conducted in the area, and urine nutrients were assumed to be lost. Average values were obtained at different levels of aggregation according to the type of farmer, site within the region and land use. The difference between farm types in area of land amended produced contrasting nutrient balances, positive for livestock managers and negative for village farmers with no or few livestock. Fallows, in general, have slightly negative nutrient balances, though fallows specifically managed by farmers of the livestock managers group have high positive values. From these results, it was inferred that other sources of nutrient inputs must have a significant effect in producing positive balances in fallows, and thus fit to the soil nutrient depletion-replenishment cycle of the crop-fallow rotation.

Figure 19. Prediction of the monthly forage selection by cattle in the study area in 1995-96 using the forage grazing model. Observed values for fallow/cropland/rangeland were 75/5/20% from June to September, 20/73/7% in October-November, 39/54/7% from December to February and 49/46/5% from March to May (data from Schlecht, 1998).

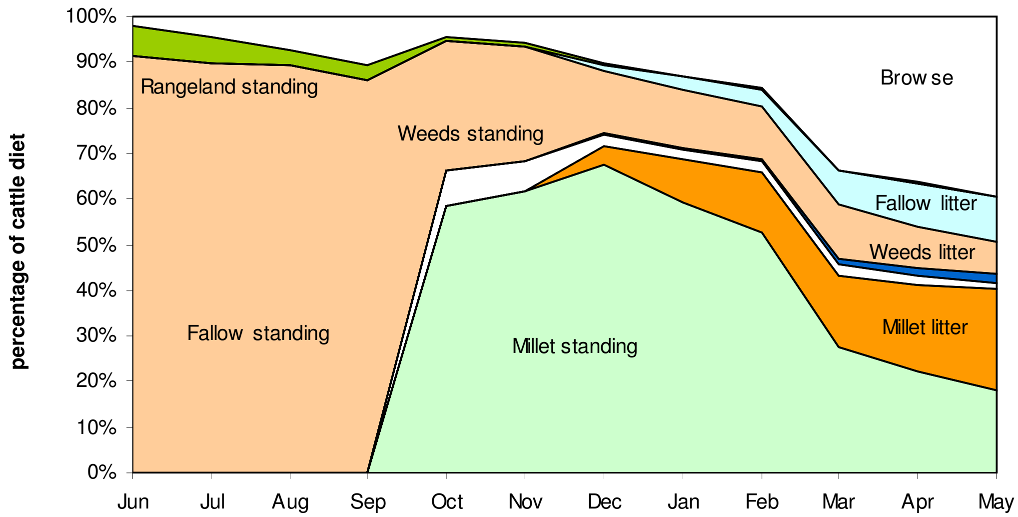
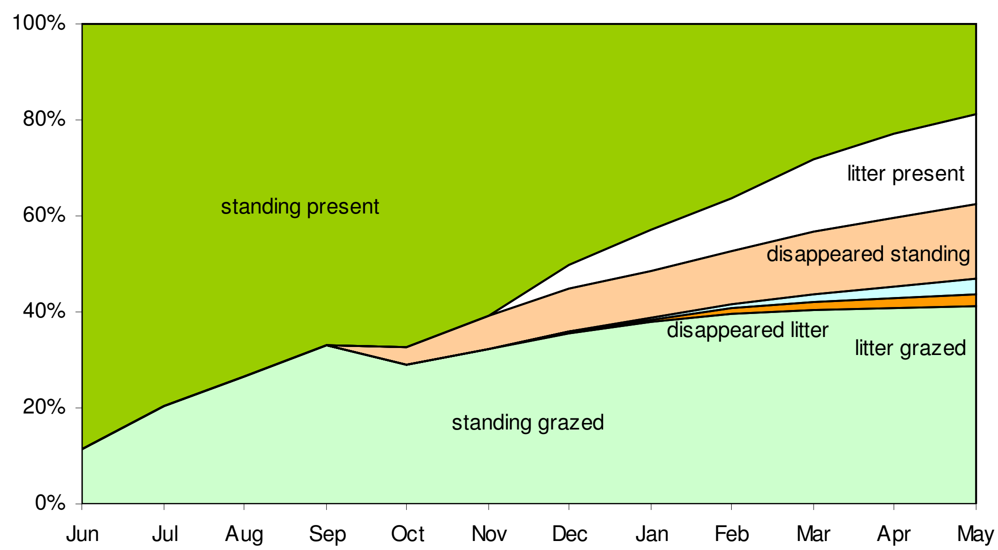


Figure 20. Predicted average percentage of vegetation components weighted for all vegetation types (millet, weeds, fallow herbaceous, rangeland herbaceous and browse) during 1995-96. Grazed and disappeared pools are expressed as cumulative values.



8.3. Options for farming intensification were explored with multi-goal linear programming by Roberto La Rovere. The model was used to explore the impact of integrated management of livestock and crops in rural communities on both the livelihoods of differently endowed farms, and on the agro-ecosystem. Different scenarios explored the co-evolution of the five farm types described in the three selected sites in Fakara with their environment. The scenarios simulate the different future outcomes for varying socio-economic and biophysical criteria with either current or more intensive management.

- In present systems, farm households that manage substantial livestock can take advantage of the use of communal grazing resources due to animal mobility. However, it was found that if current farming-ecosystems co-evolve towards increased privatisation of grazing resources, then camp farmers that have no rights on the lands are likely to resort to more distant pastures to feed their animals. Soil fertility is thus likely to deteriorate on the lands managed by camp farmers while soil fertility may improve on lands managed by the livestock-scarce farmers settled in villages, at the expense of declining farm incomes. In addition, most households will face increased labour deficits especially at peak cropping requirement periods. For the 'village poor' farms, this labor deficit could have a severe impact on the productive capacity.
- Tested scenarios of intensification of the production systems may contribute to various impacts on soil fertility, and the related food and economic security of different farms. Nitrogen balances are likely to deteriorate in most cases as a result of intensification. Intensification will tend to improve farm production and food security and income of farmers, but will not be sufficient to raise the currently most affected group, the 'village poor', which account for 40% of households away from serious vulnerability threats to their livelihoods. In addition, intensification while having the potential of reducing labour shortages at critical farming times, do not allow particularly the 'village rich' farms to meet their seasonal labour requirements. Furthermore, current seasonal national and trans-national out-migration trends toward cities and better salaries available from outside agriculture may exacerbate the already low on-farm productive capacity of particularly the 'poorer' farm households.

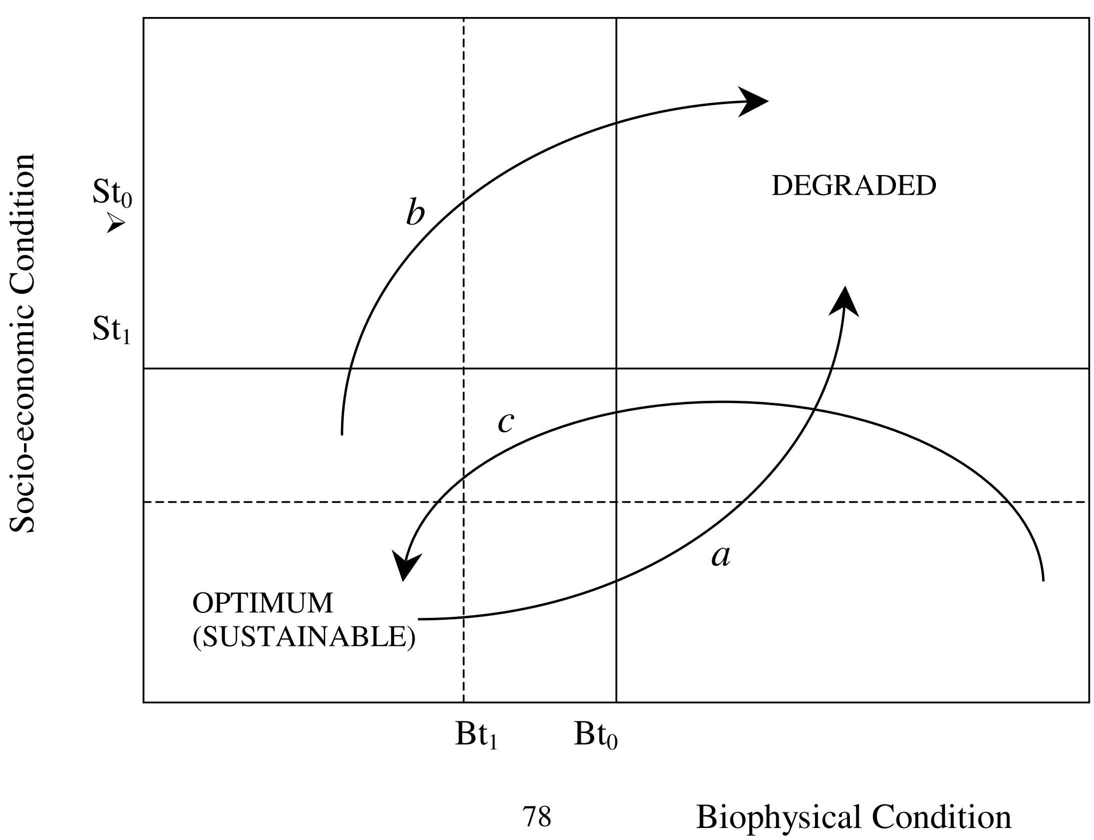
9. Prospects for the following DMP phase

9.1 From the characterisation carried out during the first phase of the project it appears that the Fakara agro-ecosystem is exemplary of the poverty-desertification nexus as proposed by Fernandez and colleagues (2002):

- Biodiversity loss is one component process of dry land ecosystem degradation.
- Desertification is a multi-dimensional problem, with many conceivable causes and a network of consequences that encompass a wide range of spatial and temporal scales.
- Degradation and restoration of a landscape are two sides of the same problem, involving both natural and social forces

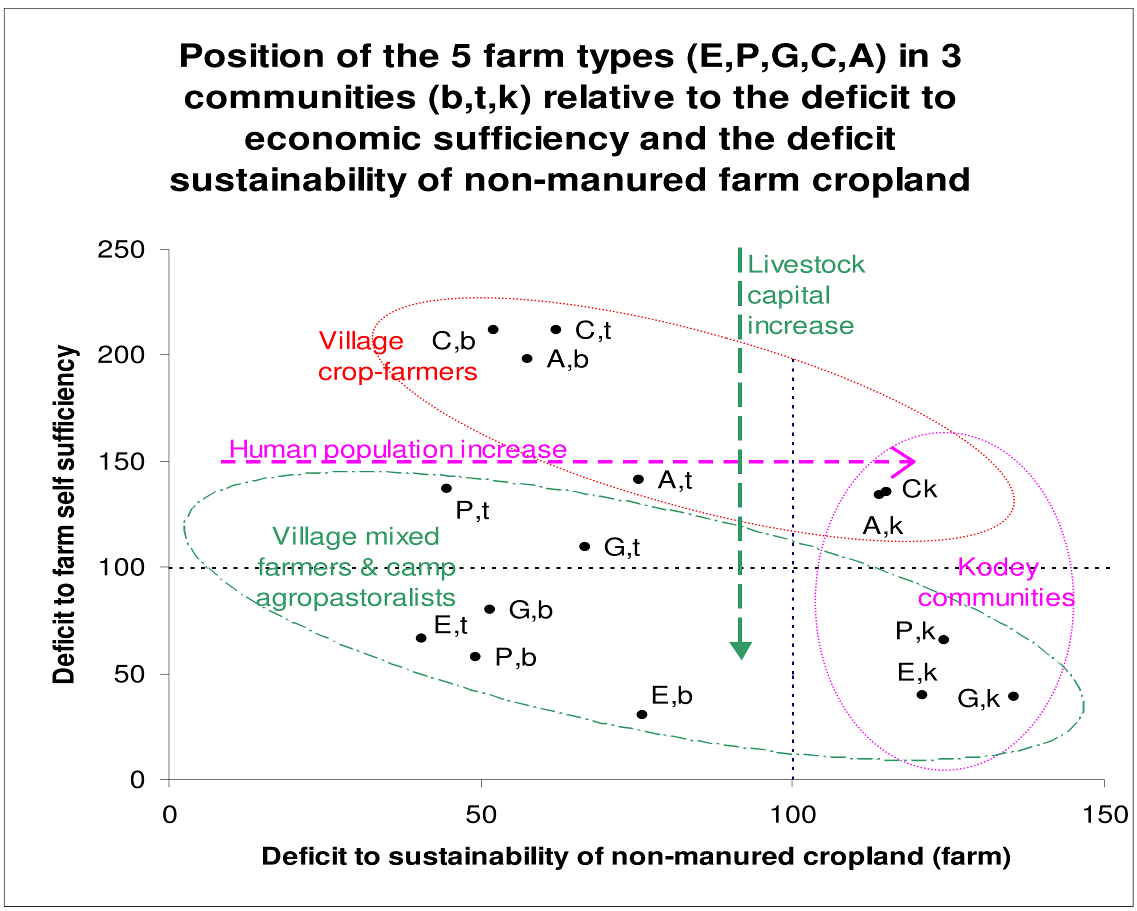
The authors argued that supplies of desired ecosystem goods and services are governed by a subset of a few variables, which include both biophysical and socio-economic one and are often variables of relatively slow dynamics. They also visualised the framework in a graph in which system component (farm, community, district) are plotted against the two axes representing the biophysical and the socio-economic variables. The thresholds on the two axes define a domain of socio-economic and environmental sustainability (down-right quadrant including the origin of the axes) and a domain of desertification (top-left quadrant beyond the thresholds; see Figure 21). The positions of the thresholds determining the actual boundaries of resilience are not fixed. They could be seen as fluctuating naturally from year to year around a certain average position. The position of the thresholds can be shifted through changes in the system and through external factors. Management and policies could contribute to expand the domain of resilience (by pushing the threshold on each axis away from the origin) and thus build and maintain the adaptive capacity of the ecosystem. This is precisely the main objective of the next phase of the DMP project.

Figure 21. Two-dimensional representation of a system's possible state.



9.2 To guide activities during the following phase of the project, an attempt was made to apply the framework to the Fakara agro-ecosystem. The farm data base was used to compute for each of the farms one index of economic sufficiency and an index of sustainability of the non-manured cropland of the farm (Hiernaux and Turner 2002). The results were grouped per farm type and site and plotted. The existing farm database in Fakara study site has been analysed in the two-dimensional graph of the possible states of the agro-ecosystem (Fig. 22). Three groups of farm types are highlighted on the graph: the village crop-farmers, who are globally in economic deficit; the livestock-endowed farms who appears to be economically sustainable both in villages and camps. The third group composed of all farm types of the Kodey site, which share unsustainable soil fertility management of their crop lands. The arrangement of the farm types at each site along the economic and soil fertility sustainability axes can be summarized by two driving forces - the demographic increase and that of livestock capital (arrows in Figure 22). Because of the seasonal mobility of livestock in and out of the site's communal land, a potentially important share of the economic benefit of livestock production is actually generated by feed resources from outside the sites. This achievement however, is not environmentally neutral. Although communal use of grazing resources impedes a clear identification of the wet season grazing pressure per farm type, the more a farm is endowed with livestock the more it will contribute to this grazing pressure being exerted locally in the community lands or regionally.

Fig. 22. Position of the 5 farm types in three Fakara sites relative to the average farm sustainability and to the index of sustainability of non-manured crop land of the farms.



9.3 The key role of increasing livestock capital to achieve farm self sufficiency and improve farm household livelihood as highlighted on the graph (Fig. 22) implies the optimisation of crop-livestock interactions within farm and at regional scale. Increasing livestock population within a farm to manageable herd size will certainly contribute to manure supply and diversification of farm assets and products along with household consumable products, especially high nutritive dairy products, and market oriented products, especially meat but also services (transport). However, it will increase labour cost, which communal institutions can reduce. It may also increase grazing pressure on the remaining rangelands if management is not adapted, which also requires communal institution arrangements. In this regard, skilled husbandry labour and adapted institutions that allow livestock seasonal migration will be key in decoupling livestock from local grazing resources. This will in effect allow for increased resilience at farm scale (but may have reverse effects at regional scales).

- Livestock assets could also facilitate access to inorganic fertilizer needed to enhance productivity and maintain agro-ecosystem sustainability. Indeed, in Fakara, N and P fertilizers inputs are required to overcome the land use threshold of 5 to 3 in relative proportions of land cropped with no manure to land fallowed. Application of fertiliser input is decided by each individual farmer. However, farmer association and political action can reduce the cost of the investment (economy of scale for group purchase, reducing transportation cost, promoting national or international trade or tax policies).
- Crop diversification, especially if towards dual purpose legumes (which help in crop-livestock integration, livestock productivity, N fixation, cash income etc.) and other cash crops (sesame, sorrel etc.) could also contribute to ease access to inorganic fertilizer through cash generation and thus help in widening the 'resilience domain' in several ways at once.
- Adapted agro-forestry activities by enhancing the production and diversity of the tree population of the agrarian park and the bushy field hedges with selected multipurpose trees and shrubs, could contribute to diversifying products, reducing grazing pressure on herbage, and helping recycling water and nutrients. Interventions in the management of agro-forestry resources imply, however, institutional arrangements as most of the tenure or the resources are mostly communal.
- The key issue in the following phase of the project is thus farmer empowerment on natural resource management. This will require major responsibilities by farmers' associations and associated services. A first step in that direction was achieved during the first phase by organising series of workshops in August and September 2002with the farmers' communities (young people, adult men and women of the two communities i.e. village and camp farms) of Fakara. Farmers were invited to express their views concerning the future of their farming system and the supporting agro-ecosystem. They were also asked to critically review the diagnostic presented and the trials results, and to give their expectation from alternative management options and the constraints for adoption. A total of 819 persons took part in the workshop. In each of 5 locations, the project team initially presented the research findings to the whole assembly in terms of production system diagnostic and results of trials conducted by the farmers, or with them on farmer's fields or herds, or on-station. The survey of opinions and the discussions that followed were held simultaneously and separately with the men, women and youths of each of the two communities i.e. village farmers, mostly Jerma, and camp farmers, mostly Fulani. The results of these workshops could very much

help focussing the future activities of DMP project. These results are summarised in a few tables below.

Table 46. Farmer's opinion on the technological options tested by the project so far.

Tested technologies	*Farmers categories*				Total[a]
	Camp[a] Men	Village[a] Women	Village[a] Young	Village[a] Men	
	%	%	%	%	%
Millet cropping					
➢ Placed fertilisation	68	91	88	100	88
➢ Selected breeds	81	66	74	90	78
Soils amendments					
➢ Corralling at low rate	97	94	60	100	88
➢ Mulch of millet stalks	54	6	18	27	25
➢ Mulch with coppices	15	9	0	0	5
➢ Placed fertiliser and corralling	80	72	70	84	76
➢ Relay application of fertiliser	36	50	4	89	47
Cowpea cropping					
➢ Placed fertilisation	9	63	0	73	39
➢ Pesticide treatments	54	80	87	100	82
➢ New cultivars	46	80	0	73	51
➢ Higher plant densities	83	0	9	94	46
➢ Alternated rows millet-cowpea	59	80	28	16	45
➢ Millet-cowpea rotation	27	88	70	61	63
Sheep fattening					
➢ 300g cowpea + millet bran	100	100	89	100	97
➢ Compost/manure	64	63	59	100	73
➢ Fattening of young and light males	89	80	71	73	78
Cattle supplementation					
➢ 720g bran + 4g phosphate	96	76	48	94	79
➢ Phosphate + urea	17	40	0	34	24
➢ Seasonal supplementation	100	37	0	100	59
➢ Supplement all year round	72	62	29	73	59
Forage woody plants					
➢ Park and hedge plantation	74	44	60	100	70
Use of animal traction					
➢ Weeding implement for donkey traction	7	97	84	94	74

[a] Proportion of individuals that declared interest in the technologies tested.

- Unsurprisingly, cheap diet for sheep fattening, fertilisation of millet at low rate, livestock corralling for moderate duration, and pesticide application to cowpea at flowering scored the highest (Table 46). On the contrary, mulching, mineral supplementation with urea and phosphate were less attractive to the farmers.

Table 47. Farmer's opinions on expected advantages from the adoption of each tested technology on yield, sale price, profitability, and output security.

Tested technologies	Expected advantages			
	Yields[a]	Sale price[a]	Profit[a]	Security[a]
	%	%	%	%
Millet cropping				
➢ Placed fertilisation	84	0	13	36
➢ Selected breeds	70	4	0	64
Soils amendments				
➢ Corralling at low rate	78	0	8	39
➢ Mulch of millet stalks	21	0	7	4
➢ Mulch with coppices	0	0	3	3
➢ Placed fertiliser and corralling	80	6	11	33
➢ Relay application of fertiliser	49	0	0	21
Cowpea cropping				
➢ Placed fertilisation	45	8	7	8
➢ Pesticide treatments	73	22	7	53
➢ New cultivars	49	8	2	19
➢ Higher plant densities	39	0	6	8
➢ Alternated rows millet-cowpea	31	0	5	20
➢ Millet-cowpea rotation	53	7	17	17
Sheep fattening				
➢ 400g cowpea + millet bran	22	83	7	0
➢ Compost/manure	65	8	2	0
➢ Fattening of young and light males	4	80	13	9
Cattle supplementation				
➢ 720g bran + 4g phosphate	34	4	22	8
➢ Phosphate + urea	17	0	2	15
➢ Seasonal supplementation	29	5	26	7
➢ Supplement all year round	24	8	32	0
Forage woody plants				
➢ Park and hedge plantation	47	9	2	11
Use of animal traction				
➢ Weeding implement for donkey traction	63	2	9	0

[a] Proportion of individuals who responded

- Higher yields remain the most common expected advantage (Table 47) especially for manure amendments and pesticide application to cowpea. Feed security is also mentioned for the use of selected breeds and pesticides, and to a less extent for organic and mineral amendments. From livestock commodities particularly fattening and reproduction, profit is often the expected advantage., And for the fattening diet, better sale price for the sheep is the expected benefit. More additional specific advantages were cited (listed in Table 48) that give some indications of the pathways for adoption and on the type of incentives that would be needed.

Table 48 Farmer's opinions on other expected advantages of the adoption of each tested technology.

Tested technologies Tested technologies	Other advantages expected from tested technologies (expressed by % of interviewed persons)
Millet cropping	
➢ Placed fertilisation	Accessibility (7); profitability (5); precocity (7)
➢ Selected breeds	Large grains (5); precocity (11)
Soils amendments	
➢ Corralling at low rate	Fertility (3); Area amended (12)
➢ Mulch of millet stalks	Accessibility (7); anti-erosive (11)
➢ Mulch with coppices	-
➢ Placed fertiliser and corralling	Precocity (7); Fertility (14)
➢ Relay application of fertiliser	Durability (5)
Cowpea cropping	
➢ Placed fertilisation	-
➢ Pesticide treatments	-
➢ New cultivars	-
➢ Higher plant densities	Fertility (14)
➢ Alternated rows millet-cowpea	Reduced competition (7)
➢ Millet-cowpea rotation	Forage (7)
Sheep fattening	
➢ 400g cowpea + millet bran	Profitability (31)
➢ Compost/manure	-
Cattle supplementation	
➢ 720g bran + 4g phosphate	Milk (6); Reproduction (17)
➢ Phosphate + urea	-
➢ Seasonal supplementation	Reproduction (17); Calf growth (6)
➢ Supplement all year round	Reproduction (14); Condition (6); health (6)
Forage woody plants	
➢ Park and hedge plantation	Multiple use (15); Fertility (12); Acacia albida (7)
Use of animal traction	
➢ Weeding implement for donkey traction	Soil tillage (25); area weeded (14)

- The lack of technical information is the first constraint identified by the farmers (Table 49). This includes information on markets as well as technical information on production, and conservation. Surprisingly this lack of information was particularly pointed out for the cheap fattening diet. As expected, cost is the constraint given each time the technology requires some external inputs as for the use of fertilisers, pesticide, or weeding implement.

Table 49. Farmer's opinions on the constraints to adoption of tested technologies .

Tested technologies	Constraints to adoption of tested technologies			
	Information[a]	Cost[a]	Benefit[a]	Risks[a]
	%	%	%	%
Millet cropping				
➢ Placed fertilisation	34	43	2	5
➢ Selected breeds	30	32	0	16
Soils amendments				
➢ Corralling at low rate	33	6	8	7
➢ Mulch of millet stalks	17	11	5	6
➢ Mulch with coppices	24	2	3	14
➢ Placed fertiliser and corralling	26	34	5	5
➢ Relay application of fertiliser	17	27	4	5
Cowpea cropping				
➢ Placed fertilisation	10	6	10	3
➢ Pesticide treatments	23	58	4	6
➢ New cultivars	32	17	4	2
➢ Higher plant densities	22	12	2	6
➢ Alternated rows millet-cowpea	30	7	3	0
➢ Millet-cowpea rotation	39	29	0	10
Sheep fattening				
➢ 400g cowpea + millet bran	66	0	0	0
➢ Compost/manure	13	10	0	0
➢ Young thin male	29	5	0	9
Cattle supplementation				
➢ 720g bran + 4g phosphate	41	16	5	8
➢ Phosphate + urea	24	0	0	15
➢ Seasonal modulation of supplements?	21	12	0	7
➢ Supplement all year round	9	34	3	0
Forage woody plants				
➢ Park and hedge plantation	37	17	5	11
Use of animal traction				
➢ Weeding implement for donkey traction	34	38	10	0

[a] Proportion of individuals that responded

- As expected, risks were mentioned for the adoption of new cultivars, mineral supplements with phosphate and urea, and also for mulching with branchlets (Table 49). When the cost mentioned as a constraint, a distinction was made between the cost and the capital required, or even liquidities at opportune time. This should be an indication for development project. Similarly, developing agencies should notice the repeated remark by the farmers of non-accessibility or unavailability at farm gate, or even at the local market, stressed for most inputs (for example, seed of selected cultivars, pesticides, agro-forestry plants, agriculture implements).

Table 50: Farmer's opinions on other constraints to adoption of tested technologies.

Tested technologies	Other constraints to adoption of tested technologies (expressed by % of interviewed persons)
Millet cropping	
➢ Placed fertilisation	Capital required (23); labour (5)
➢ Selected breeds	Capital (5); poor tillering (7); not accessible (21); sale (5)
Soils amendments	
➢ Corralling at low rate	Livestock (14); Neglecting (6)
➢ Mulch of millet stalks	
➢ Mulch with coppices	Not available (5)
➢ Placed fertiliser and corralling	Capital (20)
➢ Relay application of fertiliser	Capital (20)
Cowpea cropping	
➢ Placed fertilisation	Capital (20); Competition (8)
➢ Pesticide treatments	Capital (8); Not available (12)
➢ New cultivars	Not available (14); plant diseases (5)
➢ Higher plant densities	Not available (5); labour (2); pesticides (7); seeds (6)
➢ Alternated rows millet-cowpea	-
➢ Millet-cowpea rotation	-
Sheep fattening	
➢ 400g cowpea + millet bran	Labour (3)
➢ Compost/manure	Transport means (29); livestock (6)
Cattle supplementation	
➢ 720g bran + 4g phosphate	Capital (12); Insufficient rangelands (3)
➢ Phosphate + urea	-
➢ Seasonal supplementation	Not available (3); Capital (17)
➢ Supplement all year round	Capital (21)
Forage woody plants	
➢ Park and hedge plantation	Tenure (17); Not available (5); Irrigation (6); Labour (7)
Use of animal traction	
➢ Weeding implement for donkey traction	Capital(28); training (5); Not available (6)

- When invited to suggest alterative proposals to increase production, incomes and enhance the household's well being, the participants listed technology options or commodities in each of four domains provided: animal production, crops, soil fertility management and off farm activities (Table 51). The proposals were grouped afterwards in three categories: commodities (guinea fowl, cowpea etc.); technologies that do not require large investment (transhumance, early weeding etc.) and technologies that require external inputs (supplements, fertilisation etc.).
- The choices of commodities as well as technologies differ between social groups (Table 51). Camp men preferred livestock and related management practices (fallowing, management of the agrarian park with *Acacia albida*); women chose cash generating activities (poultry, cash crop, small trade); the

village men surprisingly rank first ranked cattle husbandry and dry season irrigated agriculture followed by request for better infrastructures (roads, wells, heath units), and finally youths limited their choices to the technologies they use in the production system (soil tillage, weeding, pesticide treatments, animal care).

Table 51: Farmers opinion on alternative technologies to increase productivity, well-being and food security of the rural households:

Commodities[a]	%	*Practices*[a]	%	*Inputs*[a]	%
Crops					
➢ Ground nut	42	Dry season irrigation	30	Fertiliser (credit)	17
➢ Sorrel	30	Early weeding	24	Implements (credit)	12
➢ Sesame	27	Thinning	24	Seeds of selected breeds	11
➢ Bambara nut	26	Early ploughing	19	Pesticide treatments	11
➢ Okra	17	Diversification	8		
Animal Productions					
➢ Chicken	43	Diversification	17	Supplement feed	54
➢ Guinea fowl	35	Transhumance	15	Veterinarian care	42
➢ Sheep fattening	28	Surveillance	12	Oxen (credit)	6
➢ Dairy cows	23	Animal health carte	7		
➢ Ducks	21				
➢ Cattle fattening	15				
➢ Pigeons	15				
➢ Cow-calf	13				
➢ Layers	5				
➢ Rabbit	5				
Soil fertility management					
➢ Planting *Acacia albida*	2	Fallow	34	Cart (credit)	12
		Mulch	33		
		Shaff recycling	7		
		Burning	5		
Off farm activities					
➢ Sowing workshop	28	'Warrantage'	3	Roads	20
➢ Handicraft (mats)	27			Clinic	18
➢ Small shops	26			Wells-boreholes	17
➢ Dairy products (butter)	4			Meal	9
➢ Milk sale	4			Gardens equipped	6
				Market place	5
				Mosque	5

[a] Proportion of the individuals that responded

- The expected advantages from alternative crop commodities were expressed in terms of yields, income and full employment, and contribution to better animal feeding. The benefits expected from the livestock options were expressed as income often spill over to increase in crop yields. Human health improvement was also mentioned as well as food security and social status. Improvement of soil fertility is naturally expected from soil fertility management, but also from specific anti-erosive measures which have implications on yields, forage resources and full employment. Finally, from off-farm activities the expectations were mainly additional income, easier access to trade facilities, full employment and improved human health

- The other constraints identified by the farmers are listed in Table 50. For crops, the major constraint indicated was seed availability, followed by labour requirements, access to credit and sufficient operational capital. The risks due to plant diseases or pests were stressed for some crops such as cowpea, okra, sesame as well as the lack of equipment to treat the crops. For livestock commodities, animal diseases were perceived as the major risks, followed by capital to invest in livestock which is associated to lack of specialised credit facilities and to the cost of feed supplements. Improved and adapted hydraulic infrastructures were mentioned for cattle while skilled labour was only mentioned by a few farmers. The access to land for cropping was indicated as a major constraint for soil fertility management, together with access to credit while off farm activities were mainly constrained by capital availability which is associated to poor infrastructure and equipment.

Table 52. Farmer opinions on farmers organisations promoted in the Fakara canton since 1998.

Questions	Farmers categories				Total[a]
	Camp men[a]	Village Women[a]	Village Youths[a]	Village men[a]	
One or several farmers organisations (FO) have been created recently in your village	*%*	*%*	*%*	*%*	*%*
Are you member or interested in joining a FO?	80	85	34	72	68
Can every farmer become a member?	50	71	22	100	63
Can every women farmer become a member?	19	100	22	100	64
Should all men be interested in joining a FO?	23	63	52	100	62
Should all women be interested in joining a FO?	6	100	22	100	61
Does joining a FO facilitate access to:					
Credit?	28	100	52	100	73
Information?	20	100	52	100	52
Labour force?	13	48	46	61	44
Land for cropping?	0	16	46	43	28
Livestock ?	0	50	52	100	54

[a] Proportion of positive answers (weighted means)

- The farmers were evasive in their answers and expressed no enthusiasm for collective actions when questioned about the associative options in case of their needs for means, capital or labour. This lack of enthusiasm was also perceived in the response to the questions about advantages of local farmers associations which is very young in Fakara (Table 52). The farmers' answers vary very much with social groups. While the village men are convinced that joining the association can help farmers, their view was neither shared by the youths nor by camp farmers who were especially sceptic about the pertinence of women associations. In fact, no camp farmer has yet joined any of the existing farmers organisations. The expectations also differ between groups: village men and women expect access to credit and to livestock to be facilitated by the farmers associations. But access to land for cropping was only mentioned by a minority, especially in women groups; women are traditionally excluded from land rights. The opinions of youths are more balanced, and camp farmers were reserved: a quarter of them recognized possible facilitation of access to credit and to information, but none admitted that farmers associations would facilitate access to land for cropping nor access to livestock capital.

Table 53. Farmer's opinion on communal institutions they wish to create or re-enforce in the Fakara canton.

	Farmers categories				Total[a]
	Camp men[a]	Village Women[a]	Village Youths[a]	Village men[a]	
Type of institution	%	%	%	%	%
Credit and saving bank	7	7	17	11	42
Input shop	12		17		29
Association for collective action			7	15	23
Agriculture development Project	2	17			20
Dairy cooperative	15				15
Producer association				14	14
Livestock farmers association	12				12
Women association		5		6	11
Veterinary clinic	7				7
Village council				6	6

[a] Proportion of positive answers (weighted means)

- The participants in all the four social groups ranked first the credit and saving bank when questioned about the communal institution that they would like to create or re-enforce in Fakara (Table 53). The input shop for crop and livestock husbandry ranks second highlighting the need to improve access to inputs. It was noticed that both women groups and camp farmers expressed interest in agriculture development projects while village men and youths preferred the traditional associations for collective actions ("Samaria" which means village council). Finally, the communities preferred the separation of associations according to different social groups: women, village farmers, livestock herders, and youths. This opinion is certainly important to consider for any project to re-enforce farmers initiative and control over natural resource management in the agro-ecosystem, which the Desert Margins Program is aiming at during the next phases of the project.

10 Major conclusions

Major conclusions of relevance to DMP-GEF objectives from the studies carried out by ILRI in Fakara over the last decade are as follow:

- Desertification is a multi-dimensional problem, with many conceivable causes and a network of consequences that encompass a wide range of spatial and temporal scales. Biodiversity loss is one component process of dry land ecosystem degradation. Degradation and restoration of a landscape are two sides of the same problem, involving both natural and social forces.
- In spite of the wide amplitude of the inter-annual changes in production and species composition, natural vegetation in Fakara and in the Sahel as a whole is remarkably resilient to droughts, as demonstrated by the spectacular spontaneous 'regenerations' of northern Sahel rangelands following the drought crises in 1973-74 and 1983-84 in the Gourma region in Eastern Mali.
- Based on the sole criteria of species richness, the biodiversity of the Sahel flora and fauna appears relatively low in comparison with other arid or semi-arid zones such as the Karoo-Namib in Southern Africa and the horn of Africa. The low level of endemism in the flora as well as the fauna may probably be due to the amplitude of fluctuations in environmental conditions at present time and during the whole quaternary, and the relative homogeneity of the soil background. Some species are locally rare, either because they are close to the limits of their distribution area or because of the small extent of their specific habitat like for wetlands or rocky outcrops.
- Inter-annual fluctuations in herbage production and species composition of the vegetation in the region could be explained by the variable pattern of rain distribution during the wet season from year to year and from site to site.
- The progressive loss of soil fertility and the fragmentation of the landscape converge to erode diversity, either because they lead to disappearance of habitats, or to severe reduction in population (i.e. the species remnants are too small and isolated to maintain the specific biomes), or because they promote a few 'invading' species to the detriment of the others.
- The unprecedented increase in rural population since mid twentieth century, and the fast build up of urban centres have profoundly changed the land use and challenged the resilience of the system. Following the population increase, land cropped expanded rapidly since the 50's without much intensification of the production system.
- The expansion of areas cropped since mid 20th century in Fakara followed the increase of the rural population, with an annual growth rate of 3.3%, has led to disappearance of savannas by 1992 which covered 44 to 77% of the site in 1950.
- The expansion of area cropped together with that of livestock population in the region have aggravated the shortage of quality grazing resource for livestock in the late dry and early wet season. The grazing pressure on the ranges during the growing season when livestock are excluded from croplands has increased considerably. Thus, mobility is important for livestock production in the Sahel, for example wet season transhumance to the arid north. This was highlighted by the results of bio-economic model validated with Fakara village databases.
- The spatial distribution of the grazing pressure, and the associated forage uptake and excretion deposition, depends largely on the land use but also on the location relative to water points, village, camps and cattle paths.

- Cropland expansion did not result in a large reduction of total animal feed resources produced on the land per annum, because millet stover and weeds yield about as much forage as rangelands. However, the major impact of land use changes is on the seasonal availability because livestock have no access to cropland during the cropping season, and on the feed quality.
- Options for agriculture intensification that would enhance farmer’s livelihood and also reverse the trend for environment degradation includes promoting the integration of crop and livestock husbandry at all scales from farm up-wards, the diversification of crop and livestock production (especially trade-oriented commodities), increased use of off-farm inputs such as inorganic fertilizer, and better integration of woody plant management with both crop and livestock activities.
- The key role of increasing livestock capital to achieve farm self-sufficiency and improve farm household livelihood implies the optimisation of crop-livestock interactions within farm and at regional scale.
- Farmer’s opinion on the technological options tested by the project so far showed that cheap diet for animal fattening, fertilisation of millet at low rate, livestock corralling for moderate duration, and pesticide application to cowpea at flowering were the most attractive. On the contrary, mulching, mineral supplementation with urea and phosphate were less attractive to the farmers.
- The lack of technical information is the first constraint identified by the farmers for none or low adoption of some of the tested technologies. This includes information on markets as well as technical information on production, and conservation. Thus, local means of information transmission is quite important to bridge this information gap such as rural radio. Cost is another major constraint given especially for the technologies that require some external inputs.
- Rural credit and saving bank is the most important communal institution the farmers would like to strengthen. The input shop for crop and livestock husbandry is also considered important, as this would improve access to inputs.
- The key issue in the following phase of the project is farmer empowerment on natural resource management. This will require major responsibilities by farmers' associations and associated services.

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