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Does the Sahelian smallholder's management of woodland, farm trees, rangeland support the hypothesis of human-induced desertification?

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Abstract

A simple theory of 'desertification' is found inadequate for understanding the complexity, diverse patterns and flexibility of farmers' responses to change in environmental conditions and population growth in the Sahel. These include long-term transitions in farming practices, in management of natural resources and in income diversification. This paper reviews evidence relating to deforestation, woodland and rangeland degradation to show that in certain areas, a transition to intensified land use, although initially involving a loss of woodland, has led to the planting or protection of useful trees on farms and maintained biomass levels. Livestock numbers have been maintained, despite declining rainfall and loss or apparent degradation of rangeland, by development of more integrated livestock, arable and marketing systems. The possibility of these trends having impact on Sahelian 'greening' is discussed.

Keywords: Deforestation; Desertification; Drylands; Greening; Rangelands; Trees

1. Introduction

For more than three decades, since the Sahel Drought of 1968–73, the concept of 'desertification' has dominated interpretations of environmental change, more especially

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those of policy makers. The institutionalization of the concept by the UN system is mainly responsible for this. The *Plan of Action to Combat Desertification* was approved at the UN Conference on Desertification, held in Nairobi in 1977; the *UN Convention to Combat Desertification* (CCD) was initiated after the Rio Earth Summit, in 1992; and this had been ratified by >150 countries when the World Summit on Sustainable Development took place in Johannesburg, 2002. Under the CCD, countries prepare and approve *National Action Plans,* in a process facilitated by the Convention's secretariat. Meanwhile, the Convention on Biodiversity structures global concerns about biodiversity loss and degradation of ecosystems, to which desertification has obvious relevance.

A policy consensus placing desertification at the top of the agenda sidestepped key uncertainties about the scientific indicators of change and the nature of the linkages between rainfall, management and environmental change. In the Sahel, these are complex (Raynaut et al., 1999). In particular, the impact of declining rainfall (between the 1960s and the 1990s) was underplayed in scenarios of human mismanagement, designed to attract funding support for technical interventions. It is primarily the failure of most of these interventions to reverse degradation of various kinds that has brought about a policy dilemma, and opened the debate to different approaches.

What is generally understood by 'desertification'? The term has commonly been employed in two ways:

- to describe biological or physical changes, but in one direction only (towards greater aridity and reduced productivity), or
- to characterize modes of management that are considered to result in these biological or physical changes.

The focus of this paper is on the second of these. Hence the question, 'Do humans cause deserts?' (Reynolds and Stafford-Smith, 2001 1026/id) embodies both the challenge and the enduring ambiguity of the concept. Desertification may be characterized as a 'suite of biogeophysical processes (Prince, 2002), each having its own indicators. Its analysis as an integrated process is problematic. Measurable *outcomes*, such as declining plant biomass, soil removal, or lowering ground-water tables, can be described and assessed using the methodologies of separate research disciplines. Climatic parameters lend themselves to sophisticated analysis. But understanding the *causes* of a management process called 'desertification' is complex because the variables interact with one another. It has proved rather easy in the past to assign pejorative labels to certain practices (deforestation, over-cutting, overgrazing, biodiversity destruction, over-cultivation, nutrient or ground-water mining). On the other hand, it is difficult to control for the effects of rainfall variability. Thus, a large scientific, policy and populist literature on the Sahel is lacking in analytical rigour with regard to causation (Rasmussen, 1999).[1] The concept is losing credibility (Warren and Olsson, 2003).

[1]A large literature on modelling the processes of deforestation either ignores the need for an agreed definition or proceeds on the basis of multiple definitions (Lambin, 1994; Kaimowitz and Angelsen, 1998; Geist and Lambin, 2001). Yet Geist and Lambin point out that both forest clearance and degradation—different processes—are implied in many usages.

From a literature which is too large to summarize, Table 1 simplifies the key problems, hypotheses and indicators. If these hypotheses are verifiable, desertification is largely a man-made process, expressed in physical or biological indicators (Mainguet, 1991; Reynolds and Stafford-Smith, 2001).[2] The agency of rainfall is unclear. There was a persistent decline in annual rainfall from the 1960s until the 1990s in the Sahel (Hulme, 1992).[3] However, by the end of the century, some increase had occurred from the very low levels recorded in the drought cycle of the early 1980s, and good rainfall was announced in both 2003 and 2004. Other rainfall parameters, such as length of growing period, occurrence of peak rainfall, and severity or frequency of inter- and intra-seasonal droughts, also have impact on farmers' activities (Mortimore and Adams, 1999), but have not been so thoroughly researched.

2. Challenges to mainstream views

Some accepted narratives of human-induced desertification have been challenged by findings from studies in African drylands (Tiffen and Mortimore, 2002). Detailed findings have been reported, and synthesized at country level.[4] The study areas included Maradi Department. Niger, and the region of Kano in northern Nigeria. Profiles of long-term change in environmental, economic and policy variables were constructed for the period 1960–2000.

These were tested at village level and used to initiate participatory, multi-level policy discussions (Mortimore and Tiffen, 2004).

Major findings of this work (which also included studies in Senegal and Kenya) were that:

- population growth led to the development of new land, and urbanization created new markets, partly compensating for the loss of export markets;
- primary production was maintained over the long term, despite variability from year to year, in terms of the output of food commodities per capita of the district population, or in a shift to higher-value crops;
- agricultural intensification, including increased attention to soil fertility management, was evident over the long term despite the moisture constraint;
- new technologies were selected, adapted, experimented and adopted within the limits imposed by climate, soil and capital constraints;
- a farmer capability for investment in natural resources was present, and incentives to invest, provided by good policy, produced a robust response; and

[2] Uncertainty persists because the process (with all its dimensions) is too complex to be analysed under experimental conditions, as can be done in managed farms or ranches in semi-arid areas of the USA and Australia. In smallholder economies, common rights to natural resources continue to be upheld, and private rights are subdivided among many millions of smallholders.

[3] Decline was recorded in five successive 30-year periods, 1931–60, 1941–70, 1951–80, 1961–90 and 1971–2000 at some central Sahelian stations (Hess et al., 1995; Mortimore, 1998, p. 79, 2000).

[4] *Drylands Research Working Papers,* 1–41, available at 〈www.drylandsresearch.org.uk〉

Table 1
Problems, causative hypotheses and measurable outcomes of desertification in the Sahel region—mainstream views

Problem identification	Hypothesis of causation	Measurable outcomes
Deforestation for agricultural expansion	Clearing dry woodland[a] for agricultural purposes permanently reduces its area, productive potential, and conservation value	1. Reduced plant biomass per unit area 2. Reduced biodiversity 3. Micro-climatic aridification 4. Reduced CO_2 sequestration 5. Increased water erosion on slopes and wind erosion on bare soil
Woodland degradation through over-exploitation	Cutting, felling, or burning of dry woodland in excess of regeneration reduces its productivity and degrades the stock. Plantations fail to compensate	1. Reduced plant biomass in stock and annual increment 2. Reduced biodiversity 3. Reduced CO_2 sequestration
Rangeland degradation	Overstocking of rangeland or failure to adjust herd movements to localized pasture conditions[b] degrades plant communities, inhibits regeneration and exposes the surface to wind or water erosion, as well as causing starvation and a reduction in livestock numbers	1. Reduced edible biomass 2. Reduced biodiversity 3. Increased water erosion 4. Increased wind erosion of topsoil and, in some areas, the re-activation of sand dunes
Biodiversity reduction	Deforestation, woodland or rangeland degradation and selective pressure on species changes habitats, leading to the decline or disappearance of plant (or animal) species	1. Species scores decline over time 2. Uncommon species become rare, or disappear, common ones more dominant
Soil degradation and erosion	Overcultivation (breaking restorative fallow cycles, repeated cultivation and crop removals without adequate fertilization), and rangeland or woodland degradation, lead to a decline in soil fertility, leading to increased exposure of topsoil to erosion, and cannot be fully reversed except in the very long term	1. Deterioration in soil physical properties, increased water or wind erosion of topsoils 2. Deterioration in soil biological properties, biodiversity and activity 3. Deterioration in soil chemical properties 4. Declining productivity in terms of economic or biomass yield 5. Increased weeds
Dessication	On rain-fed land, the withdrawal of water in excess of recharge	1. Falling subsurface water levels in wells

Table 1 (*continued*)

Problem identification	Hypothesis of causation	Measurable outcomes
	over several years leads to a falling water-table, dessication of surface water regimes (streams, pools, wetlands), and losses of plant and animal bioproductivity. Withdrawal from aquifers in excess of recharge threatens the future of those aquifers. Excess use of irrigation water relative to drainage leads to increased toxicity in soils	2. Shallower surface water, available for shorter periods 3. Reduced soil moisture 4. Increased salinity, sodicity, or other toxicity

[a]Natural woodland is assumed to be determined by climax vegetation under specific rainfall and soil conditions.

[b]Plant biomass production is assumed to be determined under natural conditions by rainfall.

- changes in the nature of the rural family and its financial management responded to new needs and opportunities.

'Success stories' of environmental management by smallholders in African drylands have been documented from five countries (including both those already mentioned and Burkina Faso: Mazzucato and Niemeijer, 2000; Reij and Thiombiano, 2003) and donor-funded projects (Reij and Steeds, 2003). Populations of 1–5 millions, and extensive areas, are involved in these cases, which should not be discounted as exceptions.[5] In some international institutions, 'people-centred development' is replacing an emphasis on technical solutions to degradation, and a policy emphasis on realizing human capacity and investment potentials among dryland peoples is being advocated (Dobie, 2001; Anderson et al., 2003; Global Mechanism, 2004).

These studies call for a reformulation of the degradation consensus which is still influential in policy circles, especially at national level. Is a transition to more sustainable ecosystem management possible, even under the harsh prevailing conditions of the Sahel, and are these experiences in certain areas indicative? Living under intensifying environmental stress and climatic risk, the responses of Sahelian peoples are characterized by social resilience, a human resource for development (Vogel and Smith, 2001; Mortimore, 2005). There is discernible progress, in some areas, towards more sustainable and productive management of natural resources. Also, a more urbanized economy, with new markets, investment opportunities, and non-farm incomes, is driving economic transition in many areas (Tiffen, 2003). The

[5]A discordance has been observed between negative interpretations of African agricultural change at the macro-scale and positive or neutral interpretations of case studies at the micro-scale (Wiggins, 2000).

decline in biological productivity, which is at the heart of desertification, is situated in this broader context, as decisions about individual livelihoods are being made.

Land use change (LUC) is the result of such decisions—how to allocate the resource, whether to invest—which are made by many agents over time. The process of LUC is expressed in land cover changes (LCC) which can be monitored by remote sensing and have significance on a global scale (Meyer and Turner, 1994). LUC measures one facet of adaptive ecosystem management, and the long-term performance of the production system provides a criterion of 'success'. We shall examine LUC in two central Sahelian locations in relation to three inter-linked degradation scenarios: deforestation, over-exploitation of woodland, and rangeland degradation.

Section 3 addresses agricultural expansion as an agent of deforestation. We review long-term LUC data on two study areas: in southern Niger (Maradi Department) and northern Nigeria (Kano Region), and also referring briefly to an area in Senegal (Diourbel Region). We ask the question, 'was this process desertification?' In its place, a descriptive and transitional LUC model is proposed. This is used to interpret regional LUC data for states in northern Nigeria. Section 4 examines woodcutting and tree management on farms, again using northern Nigerian data, to show that they are consistent with a model of transition to more sustainable practice. In Section 5, we confront the conventional view of rangeland degradation with the evidence of long-term buoyancy and increasing diversity in the livestock sector, and link this with a trend to closer integration of crop with livestock production, and a response to growing markets. Finally, Section 6 asks the question, 'can transitional LUC along the lines described have contributed to observed Sahelian 'greening'?' An experimental model is constructed at micro-scale, using historical data from the period in question.

3. Agricultural expansion as the main agent of deforestation

Deforestation assumes a prominent place in conceptions of desertification. It is understood here to mean a decline in the area of dry tropical woodland, including savanna woodland, relative to other types of land cover, including its transformation into farmland or permanent pasture (Geist and Lambin, 2001). According to FAO usage, forest and agriculture are mutually exclusive. We propose to submit this conceptualization to field evidence, and suggest that even at a general level, a more sophisticated model is required for the Sahel.

Certainly, the critical determinant of woodland decline in the Sahel is agricultural expansion (Reenberg et al., 1997; Wardell et al., 2004). An increasing cultivated fraction dominates almost every narrative of rural LUC. Thus in the managed ecosystems of the Sahel, long-term LUC was a primary determinant of secondary changes in plant bioproductivity and biodiversity. In our two regions, profiles of LCC were constructed for 40-year periods (1960–2000), as nearly as the available data permit (Mortimore et al., 2005).

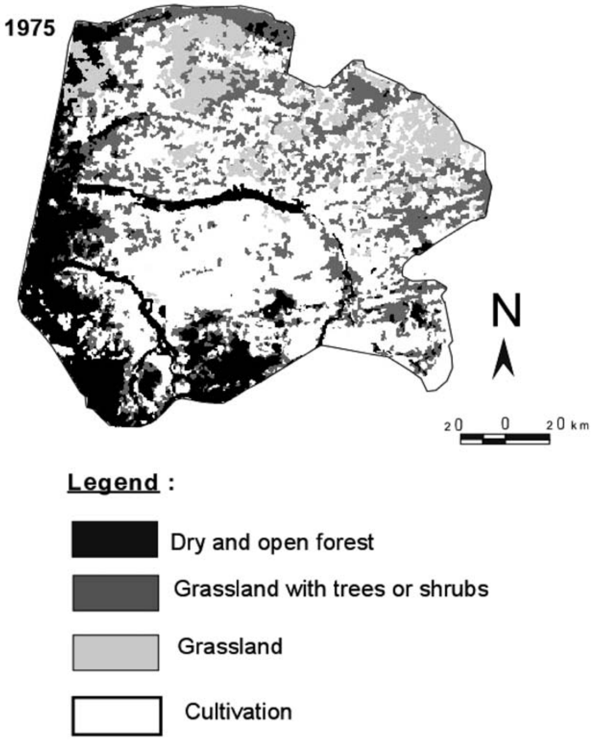


Fig. 1. Land use in Maradi Department (south of the Tarka Valley), 1975. *Source*: Air photography (Mahamane, 2001).

3.1. Maradi Niger

Dramatic landscape transformations took place over a wide area—nearly 30,000 km^2—between 1957 and the present day. An analysis of changes between 1975 and 1996 (Mahamane, 2001) shows that:

- At the beginning of the period, cultivation had already appropriated 59% of the area (Fig. 1); by 1996, the figure had increased to 73% (Fig. 2). This increase (24%) effectively completed a cycle of agricultural colonization or 'deforestation' which had accelerated as early as the 1920s, eventually creating a landscape of permanent fields and short fallows.[6]
- Some areas, still under woodland or grassland in 1975, moved with time along a gradient from 'forest' or 'open forest', through 'wooded grassland' and 'shrub grassland' to 'grassland'. Some would regard this as a pathway of degradation; if so, the transfers between classes suggest that 33% of the area mapped 'degraded' between 1975 and 1996, while 15% 'improved' in the status of its vegetation.

[6]'Cultivation' includes short fallows as well as current cultivation, as some fields are shifting.

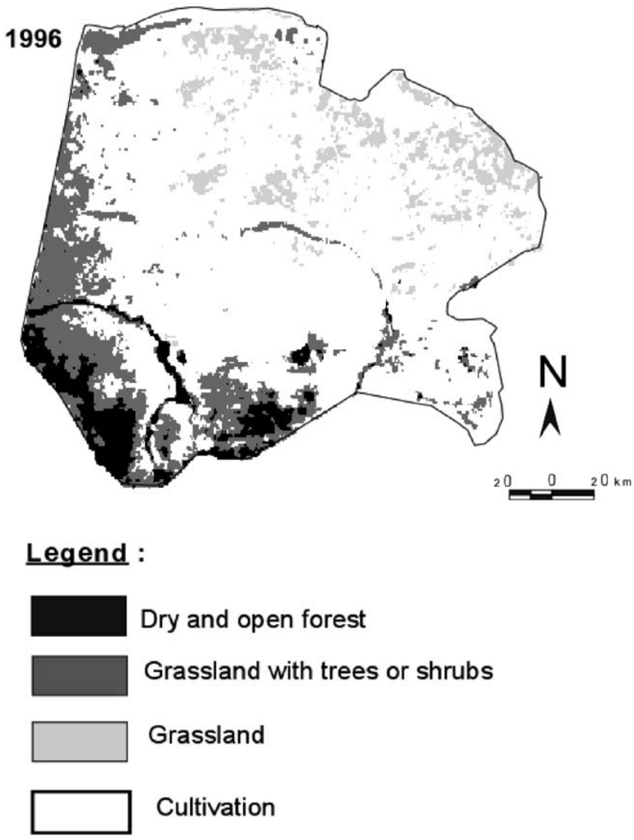


Fig. 2. Land use in Maradi Department (south of the Tarka Valley), 1996. *Source*: Resurs image (Mahamane, 2001).

Rapid in-migration and population growth, a boom in the production of groundnuts for an export market, and improving road infrastructure were among the driving forces (Mortimore et al., 2001). In Maradi, rural population density, market access and rainfall all decline northwards. However, agricultural colonization continued under declining rainfall in the 1970s and 1980s.

In Maradi Department, a gloomy prognosis was given in the aftermath of the Sahel drought of the early 1970s (Raynaut, 1980). Deforestation, soil degradation, low yields, a loss of local food sufficiency, increased dependence on out-migration and a threat to the continued integrity of the social system together created a perceived crisis. However, notwithstanding continued risk from drought, high levels of poverty and long distances to markets, Maradi maintained its grain yields (on a per capita basis) on average through the 1980s and 1990s (Hamadou, 2000). Some of this achievement was due to further agricultural expansion, but by 1996, the supply of new land was virtually exhausted. Yet the population of the department grew rapidly—between 1977 and 1988, at a yearly rate of 3.5% (Tiffen, 2001). A distinction had emerged between the south, where higher average rainfall, more labour and better market access were encouraging the adoption of more intensive techniques, and the north, where farming was still extensive and more risky (Mortimore et al., 2001).

Thus the cartographical evidence of LUC is quite ambivalent unless interpreted in the light of processes observed on the ground.

3.2. Kano region, Nigeria

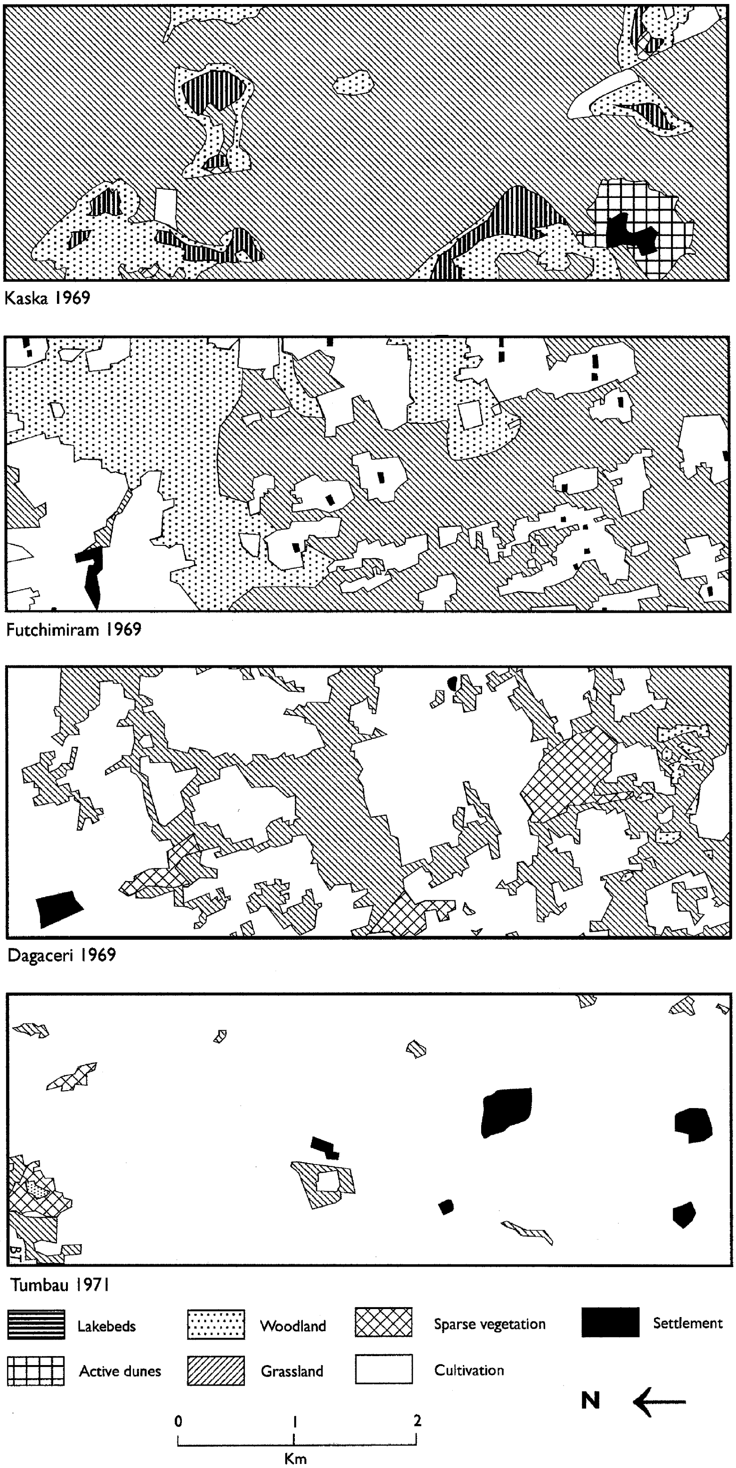
Four, widely separated, areas, were chosen, with a range in average annual rainfall from 350 to 650 mm (1990s) and in resident population density from 11 to 223 km^{-2}. Access to the regional market at Kano correlates positively with both the rainfall and the population density. In that order:

- Kaska, 350 km NE of Kano, is an area with recent severe degradation, in the form of reactivated sand dunes, in a natural grassland interspersed with depressions, partly wooded, containing saline ponds;
- Futchimiram, 440 km ENE of Kano, has shifting cultivation, with long recuperative fallows, set in open savanna woodland;
- Dagaceri, 200 km NE of Kano, has both permanent fields and some shifting cultivation with short fallows, and residual areas of degraded woodland; and
- Tumbau has long-term permanent cultivation almost everywhere, with mature farm trees, and few fallows and no woodland.

Given the force of rural population growth in driving LUC, an approximately synchronous comparison between the four locations offers a spatial analogue of LUC over time (Figs. 3 and 4). Such a comparison suggests a powerful role for the demographic factor in driving deforestation.[7] However, an examination of the detail provides a warning against generalization. Table 2 summarizes mapping of 135 km^2 in each location, using three dates (depending on sources available) between 1950 and 1990. Although all areas suffered from decreasing rainfall, and reduction in wetland areas (which have great value for dry-season farming and grazing) each farming system took its own course, and this individuality reflected a unique combination of forces, which may be summarized as follows (Mortimore and Adams, 1999):

- In Kaska, where grassland on former sand dunes dominates the landscape, and cultivation and woodland are concentrated in depressions, cultivation actually declined, while remobilized sand dunes increased, under conditions of declining rainfall, in a locally notorious case of 'desertification'.

[7]Synchronous data are difficult to achieve for such a comparison. Air photography used for LCC mapping is for 1981 at two sites and 1990 for two; population data is from the Census of Nigeria, 1990.


Kaska 1969
Futchimiram 1969
Dagaceri 1969
Tumbau 1971
Lakebeds
Woodland
Sparse vegetation
Settlement
Active dunes
Grassland
Cultivation
N
0
1
2
Km

- In Futchimiram (Fig. 4), where open savanna woodland and shifting cultivation share a less differentiated ecosystem roughly in the ratio 3.5:1, the cultivated fraction did not change in 30 years. However, an increase in grassland at the expense of woodland reflects the beginning of a transition to permanent fields.
- In Dagaceri, rapid expansion of cultivation was abruptly terminated when the competing interests of farmers and livestock producers were settled in a territorial agreement in 1972, by which time, cultivation had extended to 56.1% of the area, much of it with short fallowing, and had not changed significantly by 1981. However, grassland—fallows—expanded thereafter, at the expense of woodland (reflecting a shift into farming on the part of the pastoralists).
- In Tumbau, an ancient and stable system of annual cultivation had eliminated almost all fallowing by 1950, and the few remaining uncultivated areas were converted during the next 30 years. In its place, a highly intensive farming system based on organic fertilization, crop-livestock integration, and high inputs of labour and skills was extended to almost every plot (Harris, 1998), and the cultivated fraction is now among the highest found in Nigeria.

Diourbel Region in Senegal is superficially similar to the Kano Close-Settled Zone, having a long history of permanent cultivated fields, a high cultivated fraction, and a relatively high rural population density (up to 150 persons km^{-2}). LUC mapping shows an increase in the cultivated fraction from 82 to 87% between 1954 and 1978 (source: air photographs) and to 93% by 1999 (source: SPOT image). However, these very high figures disguise an increase in short grass fallows which is revealed in data for 1989 (air photographs) and in official land use estimates (Faye et al., 2001). Analysis of economic data shows that this was a response to agrarian stagnation, which followed a major change in policy after 1984 (the withdrawal of subsidies, credit and other forms of state support for export groundnut production). This example suggests that *décapitalization* under unfavourable market policies can threaten the sustainability of a land use transition.

3.3. *Was this desertification?*

These studies appear to describe LUC whose dominant theme is the transfer of woodland to cultivation, which (in the terms of the FAO's definition of 'forest') mainly configures deforestation. The driving forces behind this landscape transformation included an interactive mix of population growth and market opportunities, with declining average rainfall providing additional cause for

Fig. 3. Land use contrasts at four sites in the Kano region, illustrating ecosystems summarized in Table 2. From left: Kaska, Futchimiram, Dagaceri, Tumbau. *Source*: Air photography, approximately 15 km^2 at each site.

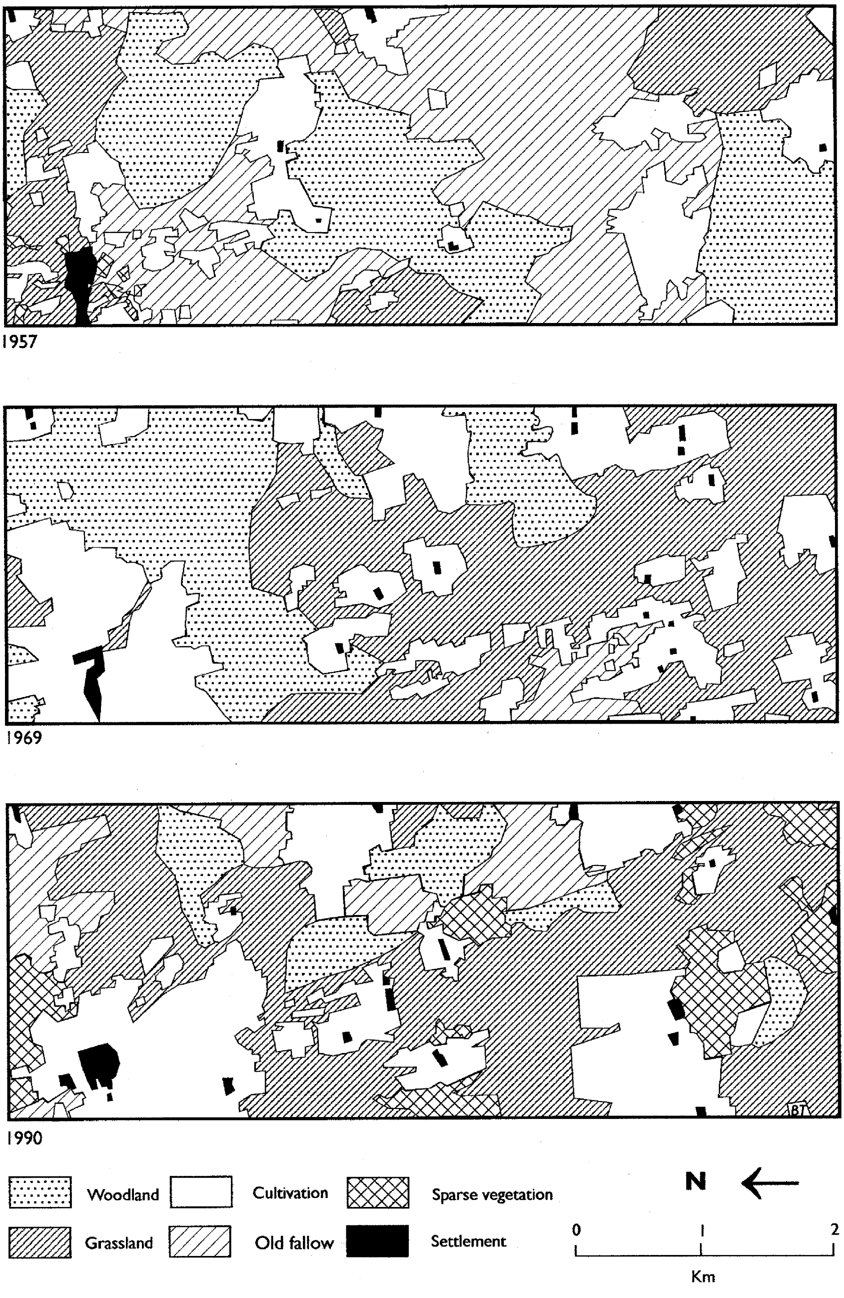


Fig. 4. Land use change between 1957, 1969 and 1990 at Futchimiram. 'Old fallow' is woodland with former field boundaries visible. 'Recent fallow' is included with cultivation in Table 2. *Source*: Air photography, approximately 15 km^2 at each site.

Table 2
Cultivation and deforestation in four contrasting ecosystems, Kano region

Land cover	Kaska		Futchimiram		Dagaceri		Tumbau	
	1950	1990	1957	1990	1950	1981	1950	1981
Cultivation (%)	15.8	10.7	22.1	21.7	35.6	54.6	77.6	88.4
Woodland (%)	16.1	9.4	30.6	7.9	3.2	1.0	0.2	1.6
Grassland (%)	63.9	52.8	46.4	62.1	57.1	32.7	17.4	0.6
Bare ground/sparse vegetation (%)	1.5	25.3	0.6	7.5	1.9	11.1	4.1	7.5
Rainfall (mm)[a]	557	286	461	286	706	429	810	573
Population (km^{-2})		11		31		43		223

Source: Air photographs, approximately 150 km^2 at each site.
Resident populations estimated from air photographs, controlled by household census (1997).
'Other' includes wetland and settlements.
[a]Rainfall: nearest synoptic station in year preceding photography.

extending cultivation per capita.[8] New, labour-saving technologies (such as animal-drawn ploughs) facilitated such an extension, while compensating, land-saving technologies (notably inorganic fertilizers) largely failed because the removal of subsidies made them less affordable.

If the decline of the forest area is equivalent to desertification, then that process should be furthest advanced where the cultivated fraction is highest, with attendant evidence of declining productivity of the biological resources. The Tumbau system in the Kano region provides a test of this hypothesis.

Tumbau lies at the heart of the Kano Close-Settled Zone, where (depending on the boundaries used) 5 million people or more support themselves from livelihoods in a majority of which natural resources play a major part. Early in the last century, according to observers, about a million people supported themselves around Kano City on a soil which had been under close cultivation for centuries. At most one-third of the farmland was under short fallow at any one time. Then as now, this was achieved through organic soil improvements: manuring, crop rotation, and green manuring, every scrap of fertilizing substance being expertly husbanded, then as now (Harris, 1998). By the 1990s, within a radius of about 50 km from Kano City, farm holdings averaged $<0.5\,\text{ha person}^{-1}$.

Field observations confirm that the cultivated fraction, all of it in permanent, manured fields, has not declined and may even have increased slightly since 1981. Fallowing is rare, and occurs by accident (sickness, labour or input shortages). Rural population densities higher than any found elsewhere in the Sahel, the proximity of a

[8]Insufficient attention has been given to rainfall decline as a driving factor in agricultural expansion. Where land preparation has low costs under hand technologies, to plant a larger area is a standard risk-reducing strategy; on the other hand, when drought is already established, further planting is pointless. Drought risk has been influential in driving farmers into greater reliance on wetland resources, though diminished in the Sahel (Raynaut et al., 1997) and in areas studied.

major regional market, a long history of relatively tranquil economic development, profitable groundnut exports from 1912 to 1975, and a culture that values industry, commerce and individual enterprise have been major driving forces. Investments by small producers continue, though alongside ever-diminishing agricultural holdings, and persistent poverty for many families. Nevertheless, there is little evidence of a collapse in yields, runaway nutrient loss, or other indicators of system failure in the longer term (Mortimore, 1993). This profile does not support a diagnosis of desertification.

3.4. An alternative to 'deforestation'

These profiles indicate that something more complex than deforestation is taking place.[9] On permanent farmland in West Africa, including the Sahel, the selection, protection and systematic harvesting of the products of 'farm trees' and shrubs are universal practices. These associations of crop production with trees in indigenous agroforestry systems, characterized by 'farmed parkland' landscapes, have given rise to their own literature (Pelissier, 1966; Pullan, 1974; Nichol, 1989; Cline-Cole et al., 1990a, b; Leakey et al., 1999). Beneficial interactions between some trees, soil fertility and livestock have been identified (Pieri, 1989). Farmed parkland evolves from natural woodland in stages which may be observed in any dynamic field situation in West Africa:

1. *Uncultivated (open savanna) woodland* is characterized by a discontinuous tree canopy over a grass and herb layer, but may be modified by grazing, burning and selective cutting. It only remains extensive where the cultivated fraction is $<70\%$, as below this line most woodland may be secondary, or recuperative fallows. Shrubs (young trees and saplings) may therefore be more numerous per hectare than mature trees.
2. *New cultivation:*[10] On clearance, extensive destruction of trees takes place, usually mainly by burning, creating an impression that the woodland has been completely destroyed. But in fact, many trees are too valuable to destroy, and are pollarded at about 2 m above the ground to prevent the crops from being shaded and seed-eating birds from roosting. During the cropping cycle, the growth of these trees continues and seedlings may be protected by the farmers (*défrichement amélioré*: Jouet et al., 1996; Awaiss, 2000). Regenerating perennials that are not wanted are cut from the fields each year, but reappear afterwards.
3. *Fallow* cycles are characterized by reversion to grassland with abundant shrubs and some scattered trees. Later (where land is abundant) they develop spontaneously to secondary woodland. Where the cultivator's rights are upheld,

[9] The reader is referred to *Drylands Research Working Papers* for greater detail (see Footnote 4).

[10] The terms 'new' and 'old' are used here to designate relative ages of cultivation, on a decadal time-scale, the former normally associated with fallowing and the latter with elimination of fallowing and its replacement by more labour-intensive farming. The term 'shifting cultivation' refers to an iterative cycling of our stages 2 and 3 (for a generic model, see Rasmussen and Molle-Jensen, 1999).

trees are still protected. It is common for fallowing to be preferred on more distant fields, while the cultivator's resources of organic fertilizer are used to transform nearby fields to more intensive use.

4. *Old cultivation:* When shifting cultivation (including 'bush fallowing') gives way to permanent fields, and fallowing consists at best of short episodes under grass, individual rights to trees and their products are fully asserted. Sapling protection is supplemented by planting of valuable species, while regular cultivation gradually reduces the frequency of regenerating shrubs. Harvesting of tree products, and use of dead or cut branch-wood for domestic fuel, becomes a more important component of rural livelihoods as the community extends private appropriation to a wider area and woodland gradually disappears. Mature trees of considerable height and canopy development come to dominate what has by now become 'farmed parkland'. Occasionally, farmers plant woodlots on some of their fields (often in response to forestry project incentives).
5. *Villages*. Trees are also planted and protected in village streets and inside compounds, for shade as well as economic benefits, creating a conspicuously well-wooded aspect. There are no shrubs.

This 'process model' sequence is linked to growth in the agricultural labour force, in the demand for consumable and marketable agricultural (and tree) products, in investments in a stable settlement pattern, and in the intensification of agricultural land use.

An evolution through two or more of these states indicates that in place of a simplistic notion of 'deforestation', a more sophisticated concept of 'tree management' is required at the local level. Changes are produced by the cumulative decisions of smallholders, appropriately described as *adaptation*, in allocating their resources of land, labour and financial capital. At the regional or aggregate level, they may connote a *transition*, which (it is argued) is being piloted by relatively intensive farming systems (Mortimore, 1998). The evolution of tree management has parallels in soil fertility management, livestock production systems, and the integration of farming livelihoods with growing off-farm income diversification.[11]

3.5. Land use change in Northern Nigeria

Data based on the interpretation of earth satellite imagery show a generalized trend of increasing cultivation in northern Nigeria (Table 3). In this table, which covers 80,420 km^2, and a relatively short period of 17 years, three levels of agricultural intensity are portrayed at state level: low (Adamawa), medium (Jigawa), and high (Kano). These levels correlate with average rural population densities, which are in turn reflected in the range of natural vegetation (grasses, shrubs or trees), which is a residual of agricultural expansion. Where land was abundant in 1976 (Adamawa), extensive agriculture thereafter gained at the expense of natural vegetation; where land was scarce (Jigawa), intensive agriculture gained at the

[11]The issues concerned with soil fertility management are taken up elsewhere.

Table 3
Conversion of land from 'natural vegetation' to agriculture by level of intensity in three states in northern Nigeria (% of state)

Category	Adamawa State		Jigawa State		Kano State	
	Low 1976–78	Low 1993–95	Medium 1976–78	Medium 1993–95	High 1976–78	High 1993–95
1.Intensive rain-fed agriculture	23	22	37	69	86	77
2.Flood-plain agriculture	1	3	8	10	1	2
3.Extensive rain-fed agriculture	25	30	39	6	3	10
4.Grasses, shrubs, or trees	47	41	9	9	6	6
5.Uncultivated wetland	2	0	6	3	2	3
Area (km^2) surveyed, rows 1–5	35,197	35,658	22,829	22,720	20,067	19,933
6.Others	2	4	1	3	2	2
State popn. Density (km^{-2} in 1993)		57		121		274

Intensive agriculture: patchwork of small, rain-fed farms with row crops and minor grazing.
Extensive agriculture: rangeland with scattered cultivated plots and denuded areas, including gullies (especially in Kano).
Grasses, shrubs or trees: forest, woodland, shrubs, grasses (Adamawa); forest, shrubs, grasses (Jigawa); trees, woodland, shrubs, grasses (Kano).
Others: presumed to include large settlements, excluded from rows 1–5.
Source: Geomatics International, 1998.

expense of extensive; and where extensive agriculture had already been eliminated by the highly intensive (Kano), there was an increase in degraded land, included under 'extensive agriculture' in Table 3 (Geomatics International, 1998). Intensive agriculture increased from 34,453 km^2 in the three states in 1976–78 to 39,713 km^2 in 1993–95. If these changes have been correctly characterized, an increasing proportion of 'deforested' land is thus entering permanent cultivation, where the 'process model' suggests the possibility of an improving perennial canopy.

4. Woodcutting and tree management

In the 1980s, woodfuel 'gaps' were estimated or projected to sensationalize a perceived risk of widespread forest degradation through over-cutting, mainly for domestic fuel for cooking and heating. Cutting was said to exceed rates of natural regeneration. Thus the impact of unsustainable use was predicted to accelerate as more and more pressure was brought to bear on forests that would diminish at an increasing rate.

In the Kano Close-Settled Zone, significant increases took place in the tree density and timber volumes between 1972 and the 1980s (Cline-Cole et al., 1990a, Table 4). This was contrary to the speculations of 'fuel crisis' advocates (Trevallion, 1966; Eckholm et al., 1984; Timberlake, 1985). High district population densities and the presence nearby of a huge urban fuelwood market (>1 million domestic consumers,

Table 4
Trees and timber on Kano farms

Land use	Air photo interpretation			Ground survey		
	Area (km^2)	Mature trees ha^{-1}		Area (km^2)	Trees ha^{-1}, 1984/85	Timber volume ($m^3\,ha^{-1}$)
		1972	1981			
Forest reserve				0.16	538	41
Farmed parkland (a)	2.0	6.1	6.7	0.1	12	69
Farmed parkland (b)	2.06	10.0	12.3	0.375	15	12
Farmed parkland (c)	6.4	7.3	7.3	0.125	11.5 (1990)	20 (1990)
Mean (a)–(c) weighted		7.23	7.78		13.7	23.2

Sources: see Appendix.
(a) Kiru District; (b) Kano Close-Settled Zone (west); and (c) Kano CSZ (east).
Note: Ground survey tends to yield higher-density estimates than air photo interpretation, as saplings are more visible. However, this has a marginal effect on timber volume.

Table 5
Trees on Diourbel farms: three villages (trees ha^{-1})

Age group	Ndiamsil Sessène	Dahrou Rahmane II	Ngodjilème
Saplings	14	71	16
Adults	2	38	4
Old	16	21	30
Total	32	130	50
No. of species	5	3	11

Source: Sadio et al. (2000).

plus industries and institutions) failed to destroy this farm tree population, even during a period which included the Sahel Drought (1972–74). At such a time, there is greater pressure on food-insecure families to cut and sell wood to raise income. In terms of timber volume, furthermore, farmed parkland may be more productive under some circumstances than reserved forest, which consists mainly of small trees and saplings.

These data derive from a period when trees were increasing in value, as markets for fruit, food, fodder, medicinal or construction products grew along with the population, urbanization, and general inflation in the economy. Gross estimates, however, do not indicate that all is well with every species or in every area. A combination of economic and drought effects produced sharp differences in the age structure and regeneration status of valued species (Nichol, 1990). In another region with long-term permanently cultivated fields, the data from three villages near Diourbel, Senegal (Table 5) show not only are there variable tree densities between villages, but also variability in regeneration and uncertain status of adult trees. The number of species is small. The more marginal status of these farmed parklands, compared with those of Kano, is probably related to the stagnation of investment in the agrarian economy in Senegal (Faye et al., 2001).

Theories that huge gaps exist between fuelwood supply and demand have fallen out of favour owing to strong methodological critiques (Leach and Mearns, 1988; Dewees, 1989; Foley, 2001). The threat to wood supply from cutting, especially for fuel, emanates from urban rather than rural demand, as field studies show that rural populations tend to be self-sufficient.[12] In the Kano region, urban fuel suppliers operate in unprotected woodland at distances of 200–300 km from the city (Cline-Cole et al., 1990a). On the face of it, this trade is damaging, as access costs (under-priced cutting licences, subsidized petrol, underpaid labour) do not reflect the market value of the wood, and pressure is increasingly concentrated on diminishing areas of natural woodland (cf. Table 2). However, pollarding selected, mature trees in mixed woodland stimulates regeneration, and may be regarded as a form of rotation; moreover, rates of regeneration have been grossly under-estimated in studies. Thus a major survey of fuelwood supply and demand in the northern states of Nigeria concluded that a 'fuelwood gap' of potentially huge proportions was opening up between demand and supply (Silviconsult, 1991), whereas stable real retail prices of wood fuel in urban areas suggested the opposite (Cline-Cole, 1998).

These and similar studies argue that rural and urban wood demands do not (as often predicted) constitute a major determinant of deforestation. In Mali, it has been estimated that the fuelwood needs of greater Bamako, rather than leading to inevitable 'mining' of forest stocks, can be supplied on a 20-year (or longer) rotation from *accessible* dry forests, while rural populations will continue to find their supplies locally. Moreover, with infrastructural improvements, the accessibility of woodland will improve well ahead of projected woodfuel demand (Foley, 2001).

5. Rangeland degradation

All LUC data show a decline in the area of natural rangeland (the grass and herb strata of Sahelian woodlands, and open grasslands or steppe), throughout the farming zones, and possibly in the northern Sahel, where rainfall has declined. Several harmful processes are believed to be linked to grazing management, such as: selective overgrazing of preferred species, soil compaction preventing regeneration, and the replacement of perennial by annual grasses (associated with the reduction in rainfall). A combination of degradation and diminution thus appears to reduce 'carrying capacity' and threaten the future of livestock production as well as of the ecosystems, e.g. in Niger, where droughts periodically decimated the cattle population (Peyre de Fabregues, 2001).

Paradoxically, however, the data available show no evidence of a long-term absolute decline in livestock numbers. While this may have occurred locally, regional

[12]This statement does not preclude the possibility that women in wood-scarce localities may expend much time and effort in maintaining a domestic supply of cooking fuel.

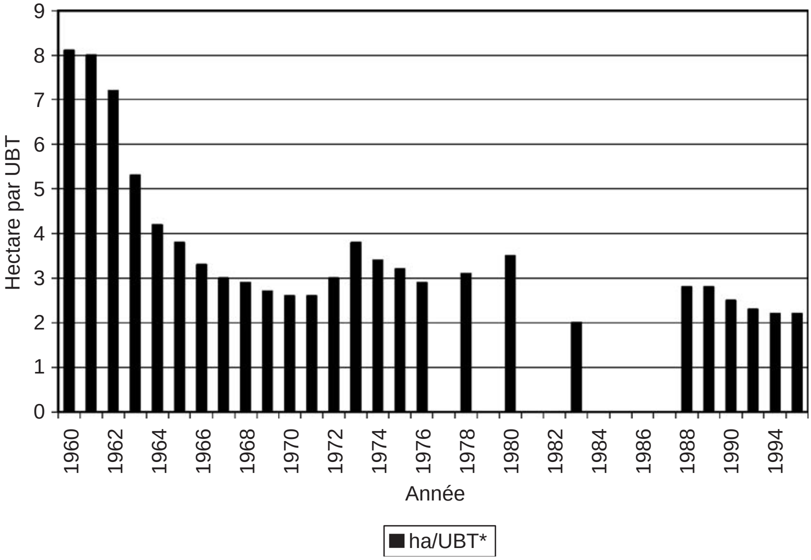


Fig. 5. Hectares per tropical livestock unit (UBT), Diourbel Region, 1960–95.

trends are stable or rising. The statistics are notoriously weak,[13] and the story is complicated by a significant shift from cattle into small ruminants (Turner, 1999). In Nigeria, estimates of the livestock population have been rising since the 1960s. In Maradi Department of Niger, official statistics indicate increasing numbers of livestock units (weighted according to species), in 1988–2000. In Diourbel Region of Senegal, a falling ratio between land and livestock units in the long term in (1960–95) would appear to herald a Malthusian crisis in the sector (Fig. 5). On the contrary, however, there was a rush into livestock fattening, buoyed by strong meat prices in an expanding economy (Faye et al., 2001). In the Kano Close-Settled Zone, a positive statistical relationship between livestock units and the human population density has existed since the 1970s (Hendy, 1977; Bourn and Wint, 1994). Animal ownership, especially of small ruminants, was increasingly sought, and fattening for market increased. Cattle, sheep and goat prices declined in real terms in Kano markets through most of the 1990s (Ariyo et al., 2001).

Farming systems that combine crop with livestock production in the drier Sahel need a minimal area of natural grazing per animal to ensure the viability of the system, according to researchers (Powell et al., 1993). As the cultivated area increases, this relationship is threatened, and with it, the capacity of the livestock to fertilize the cultivated fields. Yet in the Kano Close-Settled Zone and in Diourbel

[13]Livestock statistics depend on trust between owners who may regard disclosure of animal holdings a breach of confidentiality or bringing misfortune and officials whose use of the data for taxation purposes (or worse) is suspected. If their reliability has improved through time, this factor may discount in some measure the recorded increases. The most reliable statistics are usually considered to be those obtained from immunisation campaigns. However, an element of estimation is always present.

Region, natural rangeland has already been virtually eliminated. Farmers maintain high or rising stocking rates by using crop residues, weeds, tree or shrub browse, and (to an increasing extent) purchased fodder. 'Zero grazing' or stall-feeding is an established practice. The value of crop residues as fodder is recognized by nomadic graziers, who prioritize them over rangeland, until they are exhausted. Sedentary cattle owners, however, must send their animals away to natural rangeland when farm-produced fodder runs out, unless they can afford to purchase from the growing fodder markets. Long-distance trade in groundnut and cowpea haulms has developed in Senegal and in Nigeria. The herds of the so-called 'pastoral zone' north of the rain-fed farming frontier are also involved in these patterns of regional dependency.

In such contexts, carrying capacity estimates for rangelands are becoming redundant. Social or economic factors determine livestock holdings and movements, both locally and regionally (e.g. Turner, 1993). More complex livestock production systems are being developed by dryland farmers, against a background of declining rights to common rangeland, and threats to the sustainability of specialized pastoralism (Mortimore, 2001). However, nomadic graziers face exclusion from expanding farming areas, at least during the rainy seasons, and it has been argued that the decay of entrustment (of cattle owned by farmers to nomadic graziers) also may injure the capacity of farmers to own and manage cattle (Oksen, 2001).

On the northern frontiers of rain-fed farming, the evidence of permanent rangeland degradation is ambivalent, even in a degraded environment such as that of the Manga Grasslands on the Niger–Nigeria border. This is an area of ca.7500 km^2 of open treeless grassland, with deep wooded depressions at irregular intervals. Moving sand dunes expanded from 1% to 20% of some areas between 1969 and 1990 (Table 2: Kaska), threatening several village sites with engulfment and invading valuable lowland farms and palm groves. The grassland was transformed from dominant perennials (including *Andropogon gayanus*) to annuals (*Cenchrus biflorus*) between the 1960s and the 1980s. Open woodland declined from 17% to 5%. Large livestock populations, maintained throughout the year with little recourse to transhumance, appeared to be agents of these changes, as they selectively grazed the perennials, trampled the fragile soils, and multiplied in numbers. However, these changes coincided with a decline of about 30% in average rainfall (Hess et al., 1995), and increasingly frequent droughts. The annual grasses are highly valued by herders and probably produce as much edible biomass as the perennials; the year-round grazing capacity has not been significantly reduced; there is no clear evidence of long-term decline in livestock numbers; and in wet years, grasses and the shrub, *Leptadenia pyrotechnica* invade the dune slopes, where seed banks are continually accumulated by the wind. It is likely that the grasslands have been almost treeless since the ending of the last arid climatic phase, when they formed part of a much more extensive dunefield.

This example—notorious locally as the 'advancing Sahara'—illustrates the contradictory elements in diagnosing desertification and attributing agency (Mortimore, 1989; Reenberg, 1994; Alhassan et al., 2003). Elsewhere, ambiguities abound. For example in northern Burkina Faso, monitoring of long-term changes in the Oursi Dune from 1955 to 1995 shows recovery of vegetation after drought cycles (Rasmussen et al., 2001); and vegetative productivity gradients around wells in northern Senegal are reported to show no clear relationship between grazing pressure and degradation (Lind et al., 2003).

6. Productivity, plant biomass and 'greenness'

The crux of desertification is an irreversible (in the short term) loss of bioproductivity. Plant bioproductivity in the Sahel is characterized by both short- and long-term variability. Primary production in arid lands varies more than the annual rainfall (Le Houérou et al., 1988). Thus the vegetation boundary on the desert edge fluctuates with the rainfall (Dregne and Tucker, 1988). From the perspective of small farmers and livestock keepers, bioproductivity has three components, all affected by management: perennial, annual and subsurface. Plant biomass (kg dry matter ha^{-1}) is a measurable indicator. As the first and second are dependent on the third and are more easily accessible, most debate focuses on them. Greenness, a variable readily monitored by earth satellite, may be a cheaper and trustworthy proxy for productivity, if average annual values are generated on a regional level (Pearce, 2002). However, it is doubtful if this assumption has yet been adequately tested in field studies, as the diversity of Sahelian micro-environments is well known.

Is it possible that the kinds of management strategies described above can have an impact on regional patterns of bioproductivity, reflected in long- or medium-term changes in the greenness indices?

It has been argued from estimates elsewhere that under local conditions, farmers may produce as much plant biomass (above the ground) from their crops, fallows, weeds and trees as a natural ecosystem modelled under comparable rainfall (Breman and de Wit, 1983; Mortimore et al., 1999). This is based on two sites (Dagaceri and Tumbau, Table 2 and Fig. 3), and applies equally at these two levels of intensity and aridity. It questions the common assumption that the activities of farmers necessarily have a negative impact on the productivity of ecosystems.

Vegetation 'greenness'—averaged over the year—reflects the canopy cover of woody perennial plants and also that of annuals (field crops, grasses and herbs). Canopy cover per hectare can be estimated from historical tree density data from within the period in which LUC is being studied (Table 6).[14]

At Dagaceri, under 360 mm annual rainfall, canopy cover declined almost 40% as a result of clearing woodland for cultivation. But the cultivated areas have more trees per hectare, and the decrease in canopy was due mainly to a reduction in the

[14]Trees are visible on air photographs, which are available as systematic cover at intervals from around 1950. Even shrubs can be interpreted within acceptable margins of error. Unfortunately, in many areas, systematic air photography (which was carried out for topographical mapping) ceased 15–20 years ago Standard earth satellite data (Landsat, SPOT, etc.) has insufficient resolution to extend these profiles to the present.

Table 6
Perennial canopy by land use class: sample estimations

	1. Uncultivated land[a]		2. New cultivation[a]		3. Fallows[a]		4. Old cultivation[b]	5. Villages[a]
Mature trees								
Trees ha^{-1}	2.1[a]	7.5[c]	3.6[a]	4.1[c]	3.6[a]	2.5[c]	12.3	17.7
Canopy (m^2 tree^{-1})	21.1[a]		21.7[a]		18.5[a]		31	48.8
Canopy (m^2 ha^{-1})	45[a]	159[c]	79[a]	88[c]		46	381	863.8
Shrubs								
Shrubs ha^{-1}	138		134		134		493	0
Canopy (m^2 shrub^{-1})[d]	2.5		1.25		2.5		1.25	0
Canopy (m^2 ha^{-1})	345		165		335		606	0
Tree/shrub canopy (%)	3.9[a]	5.0[c]	2.4[a]	2.5[c]	4.0[a]	3.8[c]	9.9	8.6

Sources: air photography, 1981 (Tumbau, Dagaceri); 1990 (Futchimiram). For method, see Appendix A.
[a]Dagaceri (average rainfall, 1992–96, 360 mm).
[b]Tumbau (average rainfall, 1992–96, 533 mm).
[c]Futchimiram (average rainfall, 1992–96, 326 mm).
[d]Estimated mean values.

size of shrubs. On fallow areas shrubs increase again in size while tree numbers remain constant. At Futchimiram, under a lower annual rainfall (326 mm), there is more woodland and clearance is more recent. Tree numbers declined by almost a half under cultivation, with even fewer on fallow areas. However, canopy cover on cultivated land was similar in both areas.

At Tumbau, under 533 mm annual rainfall, canopy cover attained (at 9.9%) a level higher than that found in Dagaceri's woodland. Before dismissing this achievement as a result of higher rainfall at Tumbau, it should be noted that in the villages at Dagaceri, a comparable level (8.6%) is attained.[15]

Given the small magnitude of the estimated farmland canopies ($<10\%$) and possible increases over time, it is unlikely that slow, incremental improvement associated with the 'process model' described above took place on a scale sufficient to counteract the loss of woodland canopies through clearance.[16] However, in the Kano Close-Settled Zone, if the average canopy of mature trees is 31 m^2 (Column 4, Table 5), the tree canopy on farmed parkland (b) in Table 4 increased from 3.0% of surface area in 1972 to 3.8% in 1981.

[15]There are no woodlands in Tumbau, though further south (with >700 mm annual rainfall), canopy cover in a forest reserve is estimated to be 50%. Village sites were not estimated in Tumbau but are likely to be similar to those at Dagaceri.

[16]The sample areas used are small and uneven in size, and no general applicability is claimed for the resulting estimates. However, in Maradi Department, Niger, on several permanent fields visited in 2004, farmers reported that the numbers of mature trees had increased by a factor of about 7.5 during the preceding two decades, reaching densities of 15–20 per hectare (Boubacar Yamba, personal communication).

This suggests that annual canopies are more important contributors to 'greenness'. However, they fluctuate on a seasonal cycle. Given the available data, there is little scope for constructing profiles of change in the productivity of annuals on a decadal time-scale. Crop production data, even where reliable, does not cover total biomass. They can only be modelled on the basis of rainfall relationships. We are therefore forced to the conclusion that 'greening' from 1982 to 2002 is likely to be explained mainly in terms of increased annual rainfall.

7. Conclusion

Views of human-induced desertification, which have enjoyed extensive popularity, fail to do justice either to adaptive ecosystem management by smallholders or to the performance of their production systems. Environmental change, the magnitude of climate change in the Sahel from the 1960s until the 1990s, and the complexity of management responses, call for more adaptive models.

We have reviewed evidence from long-term studies at district scale[17] that questions whether stereotypes of deforestation, over-cutting of woodlands, and rangeland degradation are appropriate models. With regard to deforestation, a transition model of tree management, in tandem with an agricultural intensification cycle, is proposed. With regard to over-cutting (which attempts to link forest degradation with the 'fuelwood gap' hypothesis), a parallel transition in tree management on farms indicates that the problem lies in the type of resource tenure institutions, and inadequately controlled market supply chains, rather than with rural people, whose wood harvesting is normally sustainable. With regard to rangeland management, claims of degradation through over-stocking run counter to persistent long-term increases in livestock populations, driven by buoyant demand for meat, and facilitated by increasing integration of livestock with crop farming.

Transition models throw the onus onto policy makers to devise incentive structures that promote smallholders' investment and capitalization of agrarian landscapes. The Kano Close-Settled Zone represents an advanced transition, and Maradi Department (in the south) suggests an incipient transition. It is not suggested that *all* Sahelian farmers have surmounted the barriers, nor that even in Kano, land use management is ideal. However, the *trends* deserve the attention of policy makers, and could be accelerated under supportive policies. Given the impossibility of stopping the progressive clearance of natural woodland, except in uninhabited reserves of limited extent, the aim of policy should be to accelerate such a transition, in which smallholders have incentives to conserve biodiversity and biological productivity. These need not be incompatible with a dense rural population.

The implication of this analysis is that smallholders, who have to construct their livelihoods in these risky ecosystems, are the 'best bet' for a sustainable future. The main impediments to small-scale, private investments in the Sahel are risk and

[17]At this scale, which is intermediate between micro- and regional-scale analysis, we are close enough to the ground to discern process.

poverty. New technologies and management modes have a role to play, but only within these constraints. The record of the past 40 years shows that even these constraints have not prevented significant improvements to livelihoods and natural resources management in some areas (Drylands Research, 2001).

We have also addressed the possibility that such trends could already have impacted on land cover to the extent of contributing to the 'greening' seen from space during the period 1982–2002. On present evidence, management changes alone appear unlikely to have an impact on the scale necessary to explain the 'greening'. The isolation of rainfall effects is difficult. But what should be recognized is that transitions towards more sustainable ecosystem management, presently observed in a significant minority of production systems, are both consistent with the logic of scarcity in natural resources, and susceptible to manipulation by intelligent policy.

Transitions also offer a possibility of *convergence* between an evolving environmental system, subject in particular to climate change, and a human system comprising social, institutional and technical adaptations. Such a convergence, towards *synchronous* evolution of coupled systems, may be a condition of bringing an end to desertification as a biophysical process and its potentially ominous consequences for societies in risky environments (Ash et al., 2001; Robbins et al., 2001). On the other hand, *asynchronicity* leads to the certainty of either irreversible degradation of natural resources or a breakdown in livelihoods, with attendant impoverishment.

The Sahel, with African drylands in general, is too large and important an area to be ignored. Yet making links between ecosystem management on the one hand and economic and social policy on the other is very challenging. A shift in policy paradigms is currently being advocated, from the technocratic, top-down and environmentally oriented solutions of the past towards people-centred, empowering and enabling ones. To assist the smallholders in selecting the best options, the role of the public sector needs some redefinition, based on a better understanding of these complex systems of human-environment relations (Dobie, 2001; Mainguet, 2003; Anderson et al., 2003; Global Mechanism, 2004). And to deal with the speed of change, public policy also requires a level of flexibility that matches that of the Sahelian people themselves.

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Appendix. Methods used for canopy estimations

Table 4 uses published data (Nichol, 1990: 51–55, areas (a) and (b)) and data from an unpublished report (Mortimore et al., 1990, pp. 47–48, area (c)). These data were used to estimate perennial canopies for a less dry ecology, Tumbau, in Table 6. The estimates for perennial canopies in a dry ecology (Table 6) were based on tree counts at 1:10,000 on air photographs of Dagaceri and Futchimiram between 1981 and 1990. Tree crowns on two transects (888 ha in Dagaceri and 975 ha in Futchimiram) were plotted on to enlarged photographs at 1:2500, and crown diameters were measured and grouped into size classes, 5–123 m^2. They were allocated to land use classes (cultivated, uncultivated, fallow and village). Mean canopy size, total canopy ha^{-1} and % of area were calculated for each class.

Counts of shrubs, which are small, numerous and densely distributed, were made in two 6.25 km^2 quadrats (cultivated and uncultivated) in Dagaceri (*dry ecology*). As shrubs are too small to measure accurately on photographs, areas of shrub canopy were calculated using a mean size of 2.5 m^2 based on field observations. For the '*less dry ecology*', where shrubs are found along vegetated field boundaries and cattle tracks but not scattered in the fields, an estimate of the shrub canopy was based on a measurement of vegetated boundaries shown on a photograph (covering an area of ca. 60 ha) published by Nichol (1989), with a frequency of one shrub m^{-1}, of 0.5 m diameter, based on field observations.

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