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Journal of Arid Environments 70 (2007) 329–343

Journal of Arid Environments

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The possibilities of bush fallows with changing roles of agriculture—An analysis combining remote sensing and interview data from Sudanese drylands

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Received 27 March 2006; received in revised form 22 November 2006; accepted 18 December 2006
Available online 6 February 2007

Abstract

The lengths of fallows have decreased in many parts of the Sahel due to agricultural expansion, which can have negative impacts on crop production when few other ways to improve soil fertility exist. However, the dynamics of agricultural expansion may change because of the changing role of agriculture in society due to increased livelihood diversification outside of agriculture. The results of this study, which combine very high resolution satellite images and interview data, show that the role of agriculture has changed in parts of central Sudan since the crop production per capita declined substantially during the past three decades. It is argued that this decline is linked to the increase in incomes from off-farm activities during the same period. The reduced role of agriculture implies that the majority of households have more than half of the land lying in fallow; however the amount of fallow land per household varies considerably. This has specific value for the debate about *Acacia senegal* bush fallows in Sudan since with respect to the availability of land, a potential for these fallows was shown.

Keywords: Corona; Fallow; IKONOS; Land use change; Sahel; Sudan

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0140-1963/$ - see front matter
doi:10.1016/j.jaridenv.2006.12.018

1. Introduction

A majority of the world's poor live in marginalised areas such as the Sahel where rainfed agriculture is an essential livelihood, often on poor soils with low nutrient status and with low and varied precipitation. Fallows can be a key strategy for improving soil fertility and their biophysical benefits have been widely studied (Sanchez, 1995). Nevertheless, the lengths of fallow periods are decreasing in many parts of the Sahel due to agricultural expansion (Amissah-Arthur et al., 2000; Franzel, 1999; Harris, 2002; Wezel and Haigis, 2002), which can negatively impact agricultural production where few other ways to improve soil fertility exist.

There are reasons to believe that, in addition to agricultural expansion, the role of agriculture is changing due to an increase in the importance of livelihood diversification outside of agriculture (Ashley and Maxwell, 2001). Consequently, a change in the dynamics of agricultural expansion may be occurring, which is important in understanding the potential for fallows. In recent years, a number of studies on livelihood diversification have been published (Barrett et al., 2001; Carswell, 2002; Ellis, 2000). Non-agricultural income forms a significant part of diversification and it has been reported by some to have increased in importance in many parts of sub-Saharan Africa (Bryceson, 1996; Savadogo et al., 1998) while others point out that an increased awareness does not necessarily imply an increase in importance (Carswell, 2002; Ellis, 2000). This study focuses on parts of central Sudan where non-agricultural diversification as well as off-farm activities have increased during the last decades (Elmqvist, 2006).

Remote sensing is one way to study land use and land cover change such as dynamics in fallow area. Land use and land cover changes have been widely studied in the Sahel, but the analysis of the driving forces of change is often characterised by simplifications (Lambin et al., 2001; Mortimore, 1998; Reenberg et al., 1998) and a challenge for remote sensing is to validate and explain the analysis with ground data. In this study, remote sensing data have been combined with data from household and group interviews in corresponding locations. The interviews are a way of 'socializing the pixels' as expressed in Geoghegan et al. (1998) and consequently providing a deeper understanding of land cover, land use and livelihoods. Furthermore, remote sensing provides merely a snap-shot of the area studied whereas interviews can provide data over a period of time. A deeper understanding of driving forces is also gained by studying small areas (Mertens and Lambin, 1999) and therefore the focus for this study is on one village where extensive empirical material has been collected.

For studies of land use and land cover change, a long time series is crucial and therefore aerial photographs have been valuable since they are available from the 1940s. In 1972, the first Landsat platform was launched (McDonald, 1995), but it is not until recently that several satellite sensors have begun to acquire images with spatial resolutions comparable to that of aerial photography, the so-called very high resolution (VHR) imagery. One of these satellites is IKONOS whose images have been useful in mapping upland vegetation in the UK (Mehner et al., 2004) and in identifying individual trees in tropical forests (Read et al., 2003). However, the use of these images seems unexplored in drylands. Quickbird, another VHR sensor, has been successful in detecting shrubs in drylands (Laliberte et al., 2004). VHR images exist from as far back as the 1960s, an example being the satellite photographs from the American Corona programme that were important in intelligence collection and in the formation of national security policies until the programme's termination in 1972 (McDonald, 1995). The photographs were declassified in 1995 and made available to the public. Much of the Corona photography has a resolution in the 2–4 m range, with limited coverage in the 1–2 m range, and it can therefore serve as an alternative to aerial photography. Corona photographs have been used in land cover classifications in Africa and the resolution has been sufficient to count individual trees and shrubs in open field conditions (Andersen, 2006; Tappan et al., 2000) as well as to distinguish forested and non-forested patches (Wardell et al., 2003).

This study focuses on one type of fallow system, a bush fallow based on the *Acacia senegal* tree. It is mostly practised in central Sudan, but the tree grows in large parts of the Sahel. It is a rotational system with fallows lasting around 20 years (Obeid and Seif el Din, 1970). The system is advantageous in many ways: the trees improve soil fertility, the wood is valuable as firewood and as building material and its gum, called gum arabic, is a cash crop exported to Europe and the US as an ingredient in pharmaceuticals and confectionery (Barbier, 2000). Furthermore, the gum arabic is collected during the dry season when there are few other agricultural incomes and therefore potentially a significant strategy to diversify livelihoods. However, there have been several studies carried out that focus on changes in the bush fallow system, specifically on the decline of the fallow periods (Ballal et al., 2005; Larson and Bromley, 1991; Obeid and Seif el Din, 1970) due to agricultural expansion (Ballal et al., 2005) as others have found with fallow systems in the Sahel. Hence, agricultural expansion can be a threat to the *A. senegal* bush fallow system since it requires long fallow periods. If the *A. senegal* bush fallow system is no longer practised it could be disadvantageous for smallholders, the main producers, who may not have a viable alternative income. The village studied has not practised this bush fallow system since prior to the 1984 drought (Elmqvist, 2006).

The aim of this study is to examine the role of agriculture in terms of crop production, in a village where non-agricultural off-farm incomes[1] have increased, to assess the potential for practising the *A. senegal* bush fallow system. The objectives are (1) to assess changes in crop production per capita and (2) to understand whether the lack of available land at household level could be a reason why the *A. senegal* bush fallow system is no longer being practised as prior to the 1984 drought. This study focuses on the potential for reviving gum arabic production, rather than why the system disappeared in relation to the 1984 drought.

2. Study area

The study area is located in the region of Kordofan in central Sudan (Fig. 1). One village, Sararya Makawi (13.93°N, 30.53°E), was chosen based on Elmqvist (2006), as representing a village without major income from gum arabic, but where it was a main source of income before the 1984 drought. The village consists of 54 households.

The households in the region practise rainfed agriculture on sandy soils (arenosols). The main food crop is pearl millet (*Pennisetum typhoides*) and the main cash crops are sesame (*Sesamum indicum*) and watermelon (*Citrullus vulgaris*). The households practise a low level of mechanisation with only hand tools and use no traction by livestock, no chemical fertilisers and no irrigation. The livestock is comprised mainly of goats, sheep and camels.

[1]The livelihood activities are divided into agricultural and non-agricultural activities, which refers to whether the activity is within the agricultural sector or not. Thereafter, the activities are classified according to location, where farm refers to someone's own property (Elmqvist, 2006).

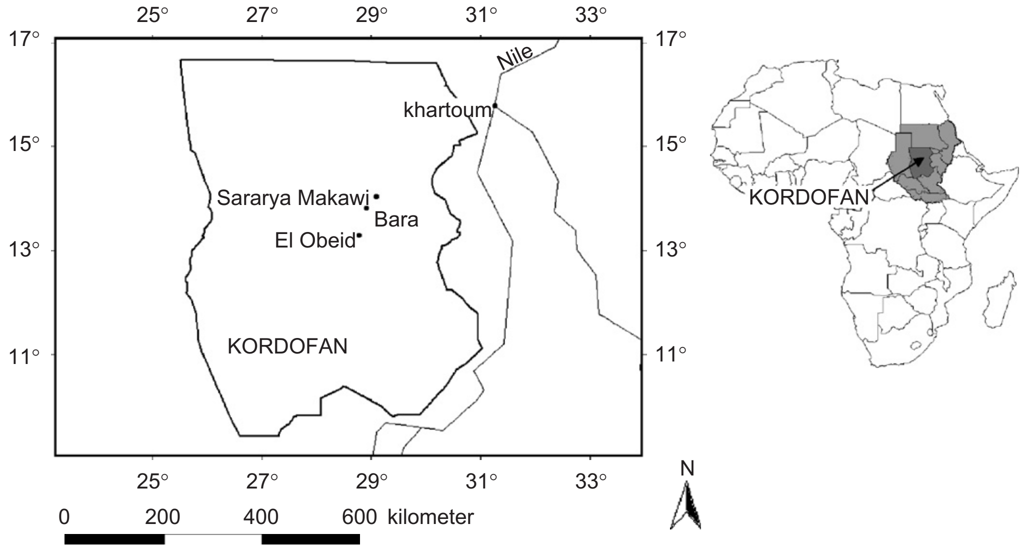

Fig. 1. The location of the village Sararya Makawi and its location in Sudan and Africa. The village is located 300 km southwest of Khartoum and the closest towns are Bara and El Obeid.

Some predominant trees are *Balanites aegyptiaca*, *Calotropis procera* and *Leptadenia pyrotechnica* and some dominant understory species are *Cenchrus biflorus*, *Eragrostis tremula* and *Aristida mutabilis*.

During the period from 1960 to1999, the Makawi area (closest meteorological station: Bara, 30 km to the south-west) received an average annual rainfall of 227 mm according to the Sudan Meteorological Department. Not only was the level of precipitation low, but also variable. Sudan suffered greatly in the drought of 1984 unlike some other parts of the Sahel where the drought in the early 1970s was more severe (Olsson, 1993).

3. Data and methods

3.1. Remote sensing

The earliest available photographs of the study area are the Corona satellite photographs dating back to the late 1960s, which were compared with recent images by IKONOS from 2002. The images were classified with an object-oriented approach into fallow and cropland, and were compared to each other. More details on this method follow below.

3.2. Field data

Field data were collected in February 2004 and 2005. Since no satellite data are available for that period, GPS-points were only collected from fields where the land use had not changed since 2002 according to the owner of the field. A total of 20 training areas and 56 evaluation areas were collected with GPS (± 6 m). The village boundary (all land belonging to the village, including settlement and fields) was delineated in the field and has been constant since the village was founded, long before 1970.

3.3. Image data and pre-processing

The study spans a time period of more than three decades: the historical photographs from 1969 were acquired from the Corona satellite and the recent images from 2002 by IKONOS (Table 1). The spatial resolutions are approximately 2 and 1 m, respectively. The panchromatic bands are used in this analysis. No radiometric correction has been carried out for any of the images since the change detection study does not compare absolute brightness (Laliberte et al., 2004).

The Corona photographs were acquired by the KH-4b mission (USGS/EROS, 2006). The photographs were acquired with film-return systems (Leachtenauer et al., 1998) and at the time of order no digital format was available. The photographs were ordered as film positives and scanned with a resolution of 3600 dpi, with an EPSON 4870 Perfection Photo. The photographs have panoramic distortions, but the study areas were not located along the edges of the photographs and therefore some of the geometrical distortions were avoided. The Corona photographs of Makawi were resampled by cubic convolution (1st order) to the IKONOS image (RMS = 5.35, 4.37). The IKONOS image was resampled by cubic convolution (1st order) with 17 ground control points (RMS = 2.20, 2.36).

3.4. Image processing

Even though there are several VHR sensors available today, it is time-consuming to interpret large areas visually, both in non-digital and digital format. An alternative to pixel-based classification for images in digital format is object-oriented classification, which recently has begun to receive recognition within land cover classification and landscape ecological analysis (Devereux et al., 2004). Image segmentation, one part of the object-oriented classification, is based on the fact that the human eye most often generalises images into homogenous areas (Laliberte et al., 2004). According to Devereux et al. (2004), results from object-oriented classification are likely to be more consistent and detailed in comparison with those from visual interpretation. The image processing applied in this study includes image segmentation and object-oriented classification with eCognition Professional 4.0 (Definiens Imaging). Segmentation is the first step in the process and is "partitioning a digital image into a set of discrete, non-overlapping regions on the basis of internal homogeneity criteria" (Devereux et al., 2004). A more detailed description of this method is found in Benz et al. (2004), Devereux et al. (2004) and Elmqvist (2006).

Table 1
Satellite images and photographs used in the analysis

Satellite	Date	Spectral resolution	Spatial resolution (m)
Corona	10 Feb 1969	Panchromatic[a]	2
IKONOS	8 Sep 2002	Panchromatic (526–929 nm)	1.0

[a]The spectral resolution is unknown.

The second step in the image processing is the classification of the object created in the segmentation. Supervised classification with training data from the field was applied to the IKONOS image (Elmqvist, 2006). For the Corona photograph, no training data were available, and the classifications were supervised by a manual selection of training areas in the images. The images were stratified into village and non-village objects, the latter being classified into two classes:

- Objects with few bushes and trees and a high spectral response were classified as *Cropland*. Intercropping is practised in Sararya Makawi but even without intercropping, some trees are present, many times for the purpose of shade. The spectral response was high in the Corona photograph since the soil was visible after the crop harvest, whereas the spectral response was oftentimes lower in the IKONOS image when millet and sesame had yet not been harvested.
- Objects with more trees and bushes growing on the land were classified as *Fallow*. Signs of prior cultivation were visible with the presence of boundaries between fields, made by branches and sand, which had been established during periods of cultivation. In general, these objects were located in between cultivated fields. This class also includes fallows without signs of prior cultivation. These areas are characterised by denser trees and bushes, but most significantly, no boundaries are present. This type of fallow land is used for grazing purposes.

The accuracy of the classification of the IKONOS image has been assessed and the Kappa values are 0.63 for the fallow class and 0.58 for the cropland class (Elmqvist, 2006). The classification of the Corona photographs could not be assessed for accuracy (see Section 4). Some uncertainties were introduced since the images were acquired in different months of the year (no other cloud-free images were available). In September, the month of acquisition of the IKONOS image, no crops are being harvested and by February, the month of the Corona photographs, the harvest is complete and even most crop residues have been harvested (Table 1).

3.5. Interviews

In 2001, structured household interviews were held with all households in the village covering the seasons from 1997/1998 to 2000/2001. The questions focused on land use, livelihoods and population. In 2004, a semi-structured group interview was held in order to understand changes since 1970. For the group interviews, the head of the village was asked to call together a group to represent the village. The group selected was almost exclusively male, which could create a bias (Bedford and Burgess, 2001), but the village power structures were followed for the sake of credibility. The heads of the villages were also asked to call elderly people for the temporal assessment (Table 2).

3.6. Combining remote sensing and interview data

Information for some of the issues studied was gathered by two methods: remote sensing and interviews. The number of households could be counted in the images since each household, which includes several houses, is surrounded by a fence. The number reached through image analysis was validated by the interviews where information was provided

Table 2
A summary of the interviews

Interviews	Time covered	Type	Respondents
Household	1997/8–2000/1	Structured	All 54 households
Group	1970–2004	Semi-structured	Group selected by village leader

on the number of households and the number of inhabitants in 1969 and 2002. In the household interviews, each household was asked about the amount of cropland and fallow land (1997–2000). The same estimations were carried out on the IKONOS image from 2002, and these estimations were then validated by comparing with those from the interviews.

4. Results and discussion

4.1. Changes in crop production

Increased crop production can occur either by expanding the cultivated area or by increasing the productivity of the land and therefore these two processes were assessed below. The following analysis refers to the area of fallow land and the remainder of the land can be considered to be cropland since the village area, the actual settlement, is negligible.

4.1.1. Cultivated area

In 1969, 81% of the land was lying in fallow according to the image classification (Fig. 2a). *A. senegal* was the most common tree species and was part of the bush fallow system (Elmqvist, 2006). Bush fallows are defined as fallow land covered with bushes and small trees (Boserup, 1965). In 2002, 62% of the land was lying in fallow (Fig. 2b). Bush fallow was common and dominated by the tree species *Balanites aegyptiaca* and *L. pyrotechnica* and not by *A. senegal*, which mainly grew on the fields for intercropping (Elmqvist, 2006). *A. senegal* is valued for improved soil fertility, but it is also one of the trees most valued for fuel wood (Olsson, 1985) and for building material, which makes the tree vulnerable to cutting. *B. aegyptiaca* and *L. pyrotechnica* are both useful as forage and building material.

According to the household interviews, the average fallow area from 1997 to 2000 was 71% (range: 68–75%). The year 2002 was not part of these interviews, but according to the group interviews there had been no significant changes in cultivated area during the immediately preceding years. Hence, the image classification could have provided an underestimation of fallow land. The classification of the image from 1969 was more difficult to validate through interviews due to the temporal gap. However, even though these estimations contain uncertainties, possible over and underestimations in both the IKONOS and Corona photographs did not affect the order of the end results, change in cropland per capita, since the differences between 1969 and 2002 were still large. The changes between 1969 and 2002 were most probably non-linear since the 1984 drought caused an event-driven change in the village during which gum arabic production was discontinued (Elmqvist, 2006) and which also impacted agriculture negatively. Non-linear

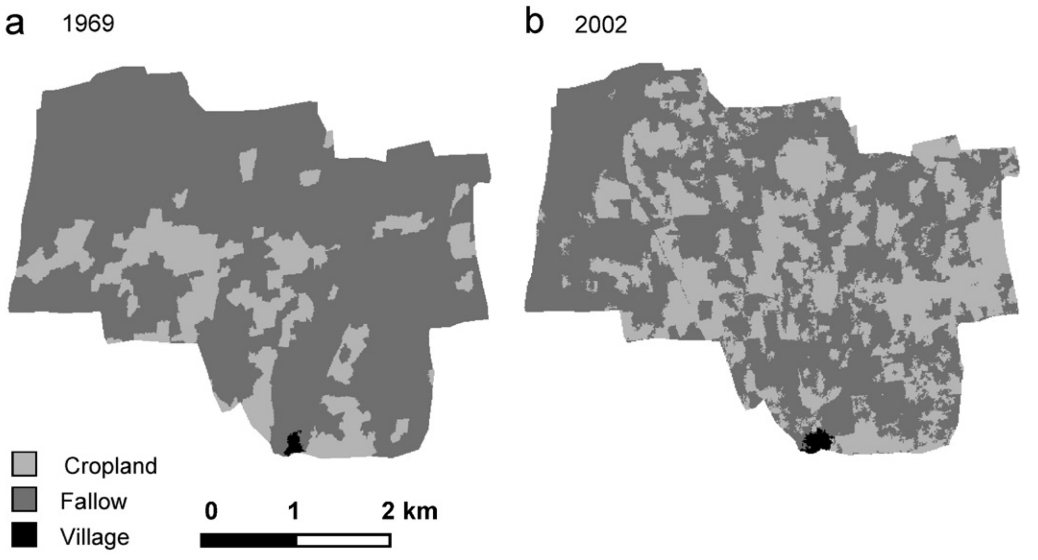

Fig. 2. Land use classification of the Corona photograph in 1969 (a) and the IKONOS image in 2002 (b). The total land area is 16 km^2.

change is often the case in the Sahel (Leach and Mearns, 1996; Mortimore, 1998; Reenberg, 2001; Scoones, 1999, 2001; Walker, 1998).

The results show a fragmentation of the landscape and an increase of the cultivated area. In 1969, the cropland was mostly concentrated in the southern part of the village and in 2002 the cropland was more scattered and was also present in the northern part (Fig. 2). The increased fragmentation of the landscape can have an impact on factors such as species abundance and movement patterns (Turner, 1989). The increase of cropland took place on land with signs of cultivation in 1969, the signs indicated by field boundaries visible in the satellite photograph. The increase also took place on land without these signs, in the north-western part of the village, which could be land that has never been cultivated. However, the two types of increases (Boserup, 1965; Oksen, 2001) are not distinguished for the purpose of this study and both processes are referred to as expansion or extensification of cropland (Kates et al., 1993). The cropland per capita does not necessarily increase, even though the total area of cropland has increased (Kates et al., 1993; Smith et al., 1994), which was confirmed in the study area. In 1969, the population of village Sararya Makawi was 41 and in 2002 the population increased to 314. Consequently, the cultivated area per capita declined from 7.4 to 1.9 ha $capita^{-1}$ during this period of time.

There are no simple relationships between population growth and the response in agricultural area (Tiffen et al., 1994) and neither is there a clear divide, expressed in number of persons per km^2, between extensification and intensification (Netting, 1993). Intensification is defined as "increased average inputs of labour or capital on a smallholding, either on cultivated land alone, or on cultivated and grazing land, for the purpose of increasing the value of output per hectare" (Tiffen et al., 1994). Nevertheless, Netting (1993) reviewed several studies from different parts of the world and concluded that a population density of 60 persons km^{-2} can be interpreted as an approximate divide between the two responses. On the land of Sararya Makawi, the population density increased from 3 to 20 persons km^{-2} between 1969 and 2002, which corresponds to an annual population increase of 6.4%. Consequently, extensive rather than intensive agriculture was most probable (Netting, 1993), but it is emphasised that intensification also takes place at such low densities since intensification can be both population and market-driven (Smith et al., 1994). This has been confirmed by Goldman and Smith (1995) who observed forms of intensified agriculture in areas with population densities under 50 persons km^{-2}. The next section assesses changes in productivity, as a measure of intensification (Kates et al., 1993).

4.1.2. Millet yields

The yield data show great diversity between years and between households. The yields were lowest in 2000, when the crops were severely damaged by pests and all but two households had yields below 20 kg ha^{-1} (Fig. 3). The highest yields were harvested in 1997 when the median was 51 kg ha^{-1}. The yields and productions in 1998 and 1999 were of the same order and in between the yields and productions of 1997 and 2000. The median production in 2000 was 6 kg (range: 0–405 kg) and in 1997 it was 900 kg (range: 0–4320 kg) per household. According to the interviews, the annual need of millet per household is 780–1248 kg millet depending on the household size, which corresponds approximately to the median production in 1997, which was the good year. This indicates that crop production could still provide subsistence in a good year. Subsistence is crucial in times of drought when the price of cereals increases drastically.

According to the group interview, the yields were currently lower than before the 1984 drought, even in years with good rain. Official data concurred and did not indicate any

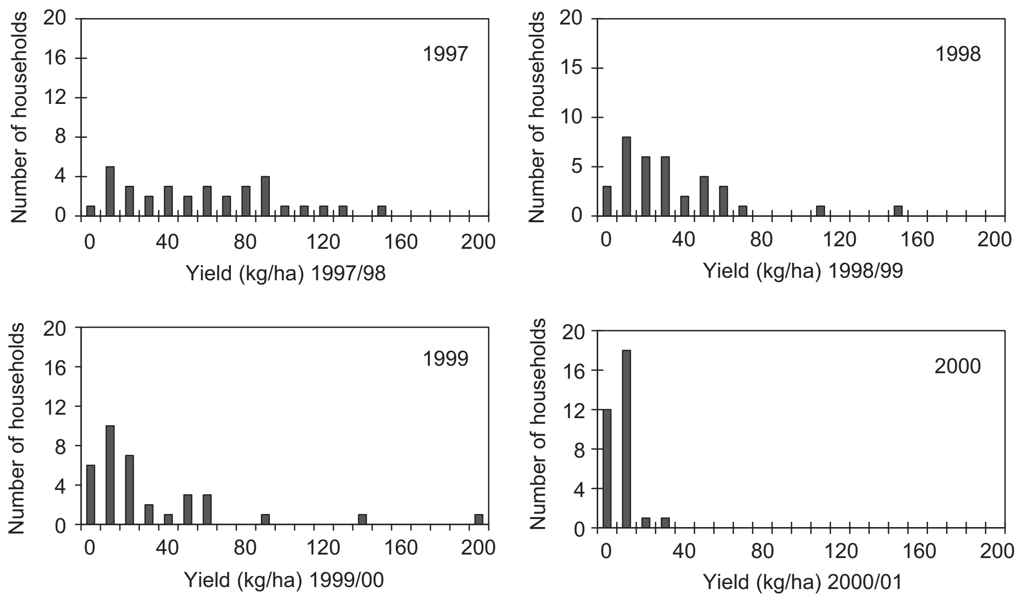

Fig. 3. The yields of millet in the households in Sararya Makawi 1997–2000 based on household interviews. The total number of households varies because the number of households not cultivating millet changed between years (1997: $n = 33$, 1998: $n = 35$, 1999: $n = 34$, 2000: $n = 32$).

increase in yields (Personal communication: E. Bashir, 2005). Thus, the decrease in cropland area and yield show that the role of agriculture in terms of production, both total and per capita, declined over the period of three decades. There are several explanations for this decline. One reason for lower yields after 1984 could be the absence of bush fallows with *A. senegal*, since it is the tree most valued for improving soil fertility (Elmqvist, 2006). Even if bush fallows were still present, the other tree species are not valued as highly for soil fertility improvement. Fallowing was one of the main strategies for restoring soil fertility, others being intercropping with *A. senegal*, growing leguminous crops such as cowpea (*Vigna unguiculata*) and stubble grazing during the dry season. There are no home gardens in the village, which otherwise could be expected to include other soil fertility management strategies. A common strategy in the West African Sahel is the targeted application of ruminant manure (Esse et al., 2001; Wezel and Haigis, 2002), the potential of which is highlighted by Mortimore (2003). However, this method is not practised in the study village. Fallowing rather than manuring has also been found in other parts of the Sahel (Reenberg et al., 1998).

A second reason for the low yields and thus the declining role of agriculture could be the expressed lack of labour as in many other Sahelian environments such as the Kano region in Nigeria (Mortimore, 2003), where labour is limited even in areas of high population densities, and in southern Ethiopia (Scoones, 2001). The informants explained that one way to reduce the need for labour is to cultivate a field that had been cropped the previous year instead of a fallow field, since cultivation of the latter field requires almost twice the number of working hours, both for millet and sesame. The most labour intensive part for millet cultivation is the preparation of the land and the first of three weedings (Fig. 4). In choosing the previously cropped field, the people value the less labour-intense option, even though acknowledging higher fertility in the fallow field. It is possible that the

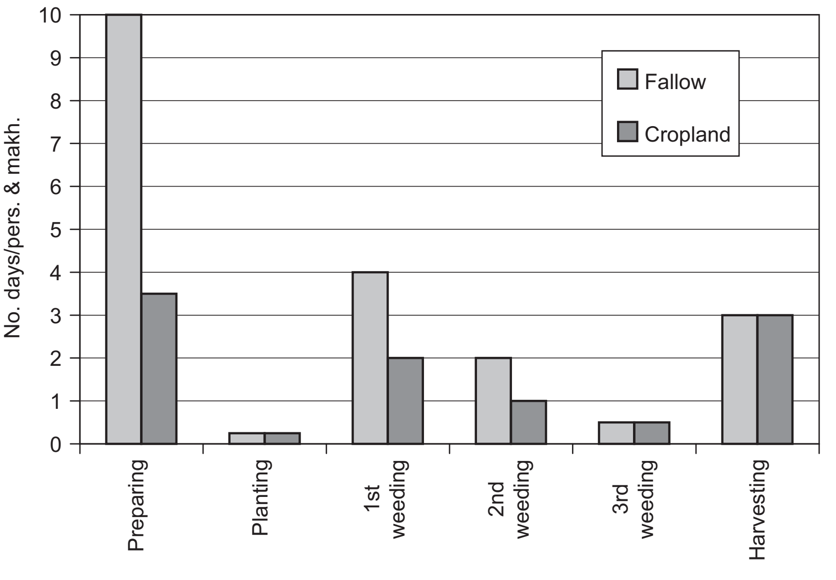

Fig. 4. The amount of labour needed for one person to cultivate one makhamas (= 0.75 ha) of millet. Fallow and cropland refer to the land use during the previous agricultural season.

unwillingness to cultivate fallow land has increased since the current trees in the fallow land are less valuable for soil fertility improvements.

One reason for labour shortage is the importance of livestock in the village, a main priority in times of economic surplus (Elmqvist, 2006) and an activity requiring labour throughout the year. The livestock composition has changed from being dominated by cattle before the 1984 drought to being dominated by goats and sheep. Also, the quantity of livestock has decreased. Another reason for labour shortage is the labour competition from off-farm activities, a livelihood that has increased during the last 3–4 decades and that is a major source of income (Elmqvist, 2006). The non-agricultural off-farm jobs involve petty trading, i.e. the selling of commodities in the informal sector in Khartoum and the agricultural off-farm jobs include date picking and other labour on larger rainfed farms. All the migrant labourers are male and the majority unmarried. The activities are mainly seasonal where the migrants return for the agricultural season (Elmqvist, 2006). However, the beginning of the agricultural season is difficult to anticipate due to erratic rainfall. In Bara, the closest rainfall station, 83% of the rainfall fell in July and August in 1999–2003, and the rest fell in May, June and September. The first rain, which is crucial for planting, varied by about 1 month (Personal communication: CARE, El Obeid). Finally, the increase of off-farm incomes could reduce the pressure to produce crops and/or the increased off-farm incomes could be a result of low crop production. It is argued that the increased off-farm incomes are strongly linked with the decline in crop production per capita and that these relationships vary considerably between households due to the high variability of incomes between them (Elmqvist, 2006).

4.2. The competition of land between cropland and *Acacia senegal* bush fallows

The information concerning proportion of fallow land per household was obtained by the household interviews and varied considerably between households. There is limited variation between the years and therefore only 1 year, 1997, is illustrated (Fig. 5). Some households had no fallow land, whereas the majority had over 50% of their land holdings

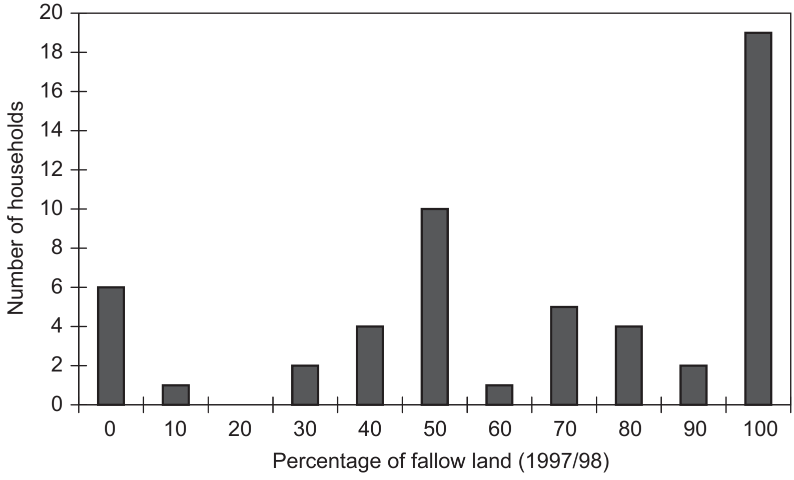

Fig. 5. The percentage of fallow land for each household in 1997 ($n = 54$).

Table 3
A schematic figure of *Acacia senegal* bush fallows according to interviews

Years	Field I	Field II	Field III
1–6	Crops (tree regeneration)	Fallow: old trees (tapping)	Fallow: young trees (tapping)
7–12	Fallow: young trees (tapping)	Crops (tree regeneration)	Fallow: old trees (tapping)
13–18	Fallow: old trees (tapping)	Fallow: young trees (tapping)	Crops (tree regeneration)

in fallow. A large number of households kept all land in fallow for the four year period in which 13 households (24% of the total number of households) had moved to other villages (for example the wife's village) and only came back to cultivate the land certain years. The median area of fallow land per household was 19 ha (range: 0–174 ha) in 1997.

In order to relate the area of fallow land to the potential of *A. senegal* bush fallows, the theoretical area of land needed was provided by interviews (Table 3) and compared to the percentage of fallow land for each household in Fig. 5. In an *A. senegal* bush fallow system the land is divided into three equally sized parts (fields I–III). The entire cycle lasts approximately 18 years and is divided into three 6-year periods (years 1–6, 7–12 and 13–18). In field II (years 1–6), trees grow on the land and are tapped for gum arabic. When gum arabic production declines the trees are cut, the land is cultivated (years 7–12) and the trees coppice and regrow. When the soil fertility declines, the cultivation stops and the trees have grown large enough to be tapped again for gum arabic (years 13–18).

Theoretically, two-thirds of a household's land needs to be in fallow in order to keep the entire land area under *A. senegal* bush fallow. A majority of the households have the potential to keep a large portion of the land under the system (even if the households with 100% fallow are excluded). This conclusion is also supported from the interviews where no one expressed lack of land as a reason why *A. senegal* bush fallows were not practised. Rather, the driving forces (both increasing and decreasing forces) of gum arabic production were expressed as drought, precipitation and gum prices as well as livestock and locusts that damage the trees (Elmqvist, 2006).

5. Conclusions

The cultivated area in the study village has increased whereas the cultivated area per capita has decreased substantially between 1969 and 2002. Bush fallows with *A. senegal* were practised prior to the 1984 drought, but current bush fallows are now composed of other tree species. The crop yields have decreased and possible reasons include the absence of soil fertility improving *A. senegal* trees and the lack of labour. Despite the decrease in crop production per capita, there are signs of its importance for subsistence, as is also made evident by the fact that all migrant labourers return annually for the crop season. The amount of fallow land per household varies considerably, but the majority of households have more than half of the land in fallow creating the potential to keep at least part of the land under *A. senegal* bush fallows. Thus, in regard to the land availability, there is a potential for *A. senegal* bush fallow in the village as practised prior to the 1984 drought due to the decreasing role of agriculture. It is argued that this decline in crop production per capita is linked to the increase in incomes from off-farm activities, observed during the same period. The use of both interviews and remote sensing enables results to be cross-validated. Further, the interviews prevent the snap-shot situation caused by having only two dates of images, which is crucial since non-linearity is common in the Sahel. For the study area and other Sahelian environments, it is important to recognise that general statements about cropland expansion are not valid when there are other profitable alternatives such as off-farm activities, which can imply an increased potential for fallows.

Acknowledgements

All households in Sararya Makawi are acknowledged. E. Bashir and all the other staff members with families at the El Obeid Research Station were acknowledged for all the assistance as well as Andrew Warren. We gratefully acknowledge the time and effort contributed by two reviewers.

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