Agricultural systems in space and time – the dynamic mosaic of land use

Anette Reenberg

Abstract

The article illustrates that the study of landscape changes requires more than land use statistics; a useful approach must be based on spatial sampling. It suggests that tracing the use of a specific unit of land through history can be an efficient way of decoding spatial messages and translating them into otherwise not detected, information about the dynamics of the agricultural resource management strategies. Selected cases from very different agroecological environments, in Denmark, Burkina Faso and Niger, are presented in order to underline the general usefulness of the approach.

Keywords

Landscape analysis, land use dynamics, land use sequences, Burkina Faso, Niger, Denmark.

Anette Reenberg: Institute of Geography, Øster Voldgade 10, 1350 Copenhagen K., Denmark. E-mail: ar@geogr.ku.dk.

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Agricultural systems analysis has had a longstanding, prominent position in the curriculum of the Institute of Geography at the University of Copenhagen. From the middle of the 20th century emphasis was laid on geographical descriptions agricultural land use and rural settlement structure (Kampp 1959, 1960, 1963, 1971) as well as on historical analysis of the cultural landscape in rural areas (Hansen 1964). In the late 1960s a new line of thought within the agricultural geography that emphasises ecological aspects of agricultural production strategies was introduced (Christiansen 1967). The focus for research and teaching was directed towards issues related to analysis of circulation of matter and energy within the systems, use of different landscape units, allocation of labour, nutrient transfers between different land units etc (Bennekou et al. 1974; Christiansen 1975, 1978, 1979; Rasmussen 1979). It had a significant influence on teaching and research among the staff members for whom the scientific focus was the man-environment interaction in agricultural production systems.

A classical case study from Borris and Sdr. Felding parishes in Jutland, Denmark (Jensen & Jensen 1979) which has been widely used in teaching, landscape administration and other research works, was inspired by these ideas. At the same time, the approach incorporates the traditions for rural landscape studies (Hansen 1964, Fredningsstyrelsen 1983). Thus, it represents a useful, innovative and interesting combination of an analysis of the dynamics of the agricultural systems rooted in the systems approach to ecology, with a corresponding analysis of the land use dynamics and its relation to the landscape. It focuses on how various enabling and constraining conditions in the biophysical and socio-economic environment interact in shaping the rural landscape. Thus, it offers a way of looking at the rural landscape and its inherent dynamics which is very valuable in the context of planning for and maintaining nature qualities in the rural landscape.

Many of the agricultural geography's most compelling questions centre around changes in the landscape; geography's way of looking at it's objectives through the lenses of place, space and scale is a well developed set of perspectives (Haggett 1990; Rediscovering Geography Committee, 1997). On this ground it is of specific interest to dwell with this single aspect of the ecological geographical approach to agricultural landscapes, although it should be remembered that the quality of such considerations only are maintained if they constitute a part of a larger analytical framework as touched upon above.

Thus, the aim of this article is limited to illustrate that the study of landscape changes requires more than land use statistics; a useful approach must be based on spatial sampling. The rather banal idea of tracing the use of a specific unit of land through history can be a most enlightening exercise – however simple it might be, it has proven its value in many different cases as an efficient way of decoding spatial messages and translating them into important, and otherwise not detected, information about the dynamics of the agricultural resource management strategies. Selected cases from very different agroecological environments will be presented in order to underline the general usefulness of the approach.

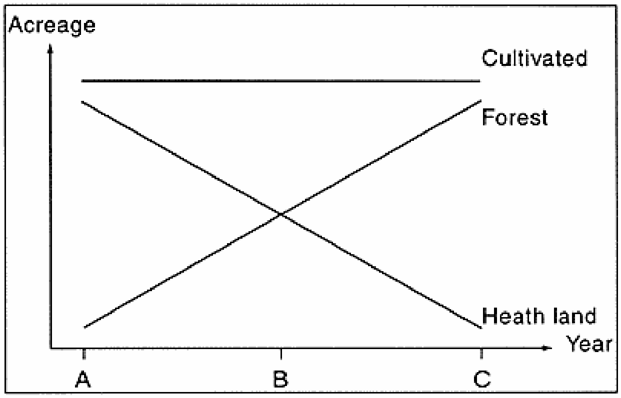

Figure 1: Development trends for major land use classes, as read from the statistics, in central Jutland from year A through B to C (resampling a scenario from mid-1800 to 1970). C= cultivated land; F=forest or plantation; H= Heath land. From Jensen & Reenberg (1980).

An educational example from Denmark

During their first year at University, geography students are introduced to the classical discipline of cultural landscape analysis. They work with Danish cases and take their point of departure in the rich material offered by topographical maps. The evolution of the Danish cultural landscape in a hundred years perspective is monitored and its interplay with the ever shifting conditions and strategies for the agricultural production is analysed (see e.g. Jensen & Reenberg 1980, Jensen & Kuhlman 1989, Reenberg 1995, Reenberg & Pinto-Correia 1994).

Many other examples could be brought forward to illustrate how shifting conditions and traditions for agricultural production through history have resulted in alternating priorities given to use of different landscape units. One example can serve to illustrate the point. Jensen (1976) has made a major study of the afforestation on the central part of Jutland. Thus, even before the emergence of the European debate on marginalization of farmland is was realised that substantial parts of the cultivated land in the less fertile parts of the country were gradually turned into forest. Little was, however, known about the spatial dynamics of landscape changes that followed from this alteration.

Land use statistics or maps?

A look into the land use statistics covering the region under investigation reveals a development path for the three major land use classes (forest, heath land, cropland) that roughly resembles the trends sketched in Figure 1. The immediate reading of the information would be; that the cultivated land had remained constant throughout the hundred years under observation and that heath land has been replaced by forest. This is, however, not at all the correct picture of what happened. The real process of change is illustrated in Figure 2. The cultivated fraction of the landscape that appeared stable in the statistics has areawise been unaltered, but its location in the landscape has completely changed.

If we move from the sketches of principles in Figure 1 and 2 to real world observations in Figure 3, some important facts about the process of heath and wetland reclamation, marginalization and afforestation can be made. The map in Figure 3 is based on a sequence of topographical

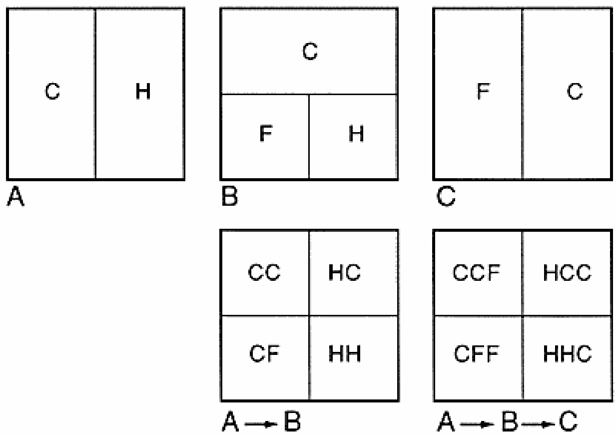

Figure 2: The three upper quadrants represents the land use maps corresponding to the statistics shown in Figure 1. The location of the different land use categories change from year to year. The corresponding land use sequences are summarized in two lower quadrants. From Jensen & Reenberg (1980).

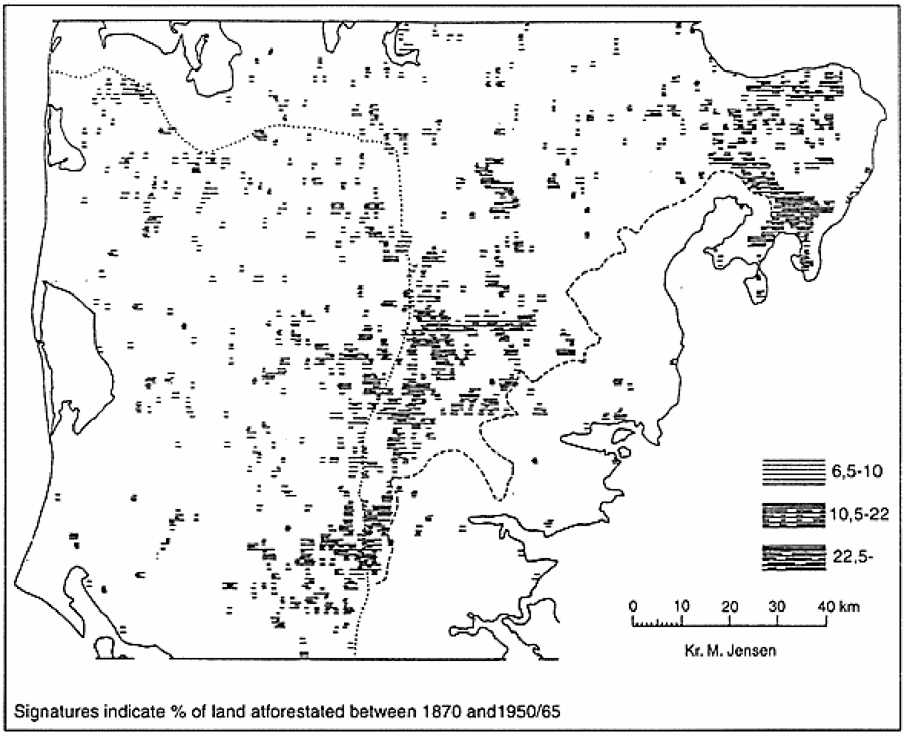

Figure 3: Land use changes in central Jutland. Based on a 1 square kilometre grid, Jensen (1976) has monitored land use alterations from 1870 to 1950. The map summarizes land use change classes that involves afforestation of former cultivated land. From Jensen's personal archives, based on Jensen (1976).

maps. For each spatial registration unit (equal to a 1 km² grid cell) the land use sequence has been recorded as illustrated in Figure 2. As it appears the spatial alterations in land use have been considerable. The agricultural land use pattern has been specifically dynamic and fluctuating in central part of the region – e.g. in the transition zone between the fertile morainic soils in the east and the outwash plains in the west.

Lessons learned for the spatial message

A proper decoding of the spatial massage given in the map urge a perception of the landscape dynamics that base itself on a complex web of forces driving land use changes. The process of change cannot be ascribed to a unidirectional land use change trend. Different landscape units will give rise to different trends. The relative land use stability in the fertile land is not a surprise. It might be contrary to intuitive expectations, however, that the most significant marginalization in terms of afforestation of former cultivated land takes place in the intermediate zone, where the soils are less sandy than the soils on the outwash plains further to the west. This can be ascribed to biophysical as well as to cultural conditions for agricultural development. Although the soils in the central zone do not belong to the lowest ranking according to the Danish soil classification, the location at the main stationary line for the last glaciation period implies that soils are generally coarse, variable in quality and leached. Furthermore the accessibility to water for irrigation is not good. They are in other words not specifically attractive for agricultural purposes and the economic benefit is very sensitive to minor fluctuations of weather, market prices or subsidies.

The substantial afforestation of cultivated land can, however, also be explained by factors that do not primarily concern the environmental production conditions. The central part of the study region is adjacent to the very fertile soils in the east. This has undoubtably influenced the land use history. In the cultivation expansion phase in Danish agriculture in the middle of the 19th century attention was in the beginning given to land bordering the already cultivated land. The vast heath lands in the western part of Jutland were until then almost entirely uncultivated land. As the demand for land increased, they became an obvious target for reclamation, starting in the eastern fringe adjacent to the old farmland on the morainic soils. In the early phase of expansion most land was uncritically cultivated, with the result that the less suitable soils had to be abandoned soon after. Later on, at a time when also the outwash plains in western Jutland were subject to agricultural expansion, the lesson has been learned and less suitable soils were not reclaimed but rather afforestated right from the start.

These complicated mechanisms have to be understood if the historical development of the agricultural landscape should be explained. In addition, knowing the dynamics of landscape changes is a crucial precondition for those who are concerned with impact assessment and evaluation of the resilience of the rural landscape under conditions of changing environmental or economic conditions.

Disentangling adaptive strategies in Niger

The second example pays likewise tribute the simple notion of land use sequences as a means to avoid overlooking important traits of agricultural strategies. The case is taken from the eastern part of Niger. The agro-ecological conditions in the region around Goudoumaria can be characterized as being at the border for cultivation. Specifically, the erratic and scarce rainfall constitutes a major constraint. However, farmers cultivate millet and sorghum and to a certain extent also cowpeas (Reenberg 1994). The landscape offers two main units that can be used for fields: low lying valleys with relatively fine grained soils, scaped by a former hydrological network; and sandy dunes, characterized by their coarse sandy soils.

The classical myth of land use alteration

Land use trends in the Sahel are frequently described as consisting of a gradual expansion of cultivated land at the expense of fallow or pastures. It is generally supposed that larger fields are needed to meet the requirement of an increasing population as well as to compensate for declining yields in the region, caused by desiccation or by depletion of soils (e.g. Scott 1979; Krings 1980; Greenland et al. 1994).

If the site specific monitoring of land use sequences is applied to the test case in Niger, we will, once again, find that important characteristics of the land use dynamics will be brought to the light. Figure 4a and 4b show the field pattern and their relation to the two main landscape elements in the years 1975 and 1986 respectively in a small test zone. Although the two maps are not geometrically corrected and suitable for overlaying, a visually based identification of alterations in land use patterns is possible - following the same map shifting principles as the ones applied on the Danish example described above. What appears is that fields are changing, not only in size but also as regards their spatial location. Following the expected trends a certain increase in the overall acreage can be observed. More interesting, though, is that land in the valley zone is abandoned and fields encroach on the sandy soils in the dune landscape.

Figure 4a: Field pattern dynamics in southeastern Niger, near Goudoumaria. The land use map from 1975 is based on a visual interpretation of aerial photos. Fields are hatched. Black areas are temporary lakes, asterixs indicate village locations. The delimitation between the two major landscape units (the undualting dunes and the valley system) is shown with a dotted line. From Reenberg (1994).

Decoding the spatial message

Cultivation primarily takes place in the valley zones. The pressure on land is generally low, and shifts in field location are possible and normally occurring; fields in the valleys are abandoned while at the same time new parts of the valley zone in cultivated. In the course of the ten year under consideration one can, however, also observe the emergence of an interesting new land use/landscape rela-

Figure 4b: Field pattern dynamics in southeastern Niger, near Goudoumaria. The field pattern in 1986 appears from the satellite image (Landsat TM, first principal component calculated fromchannel 2,3,4 and 5). The fields appear as light grey spots, with a 'scarred' texture. A few characteristic examples of land use change are indicated: (d) new cultivation on the dune; (a) abandoned field in the valley; (n) new field in the valley. From Reenberg (1994).

tionship. New cultivations appear on the dune in 1986, and a later check in the field shows that this trend is continued and enforced.

The change in strategy is farmers' rational adaptation to decreasing rainfall. Contrary to what might immediately be expected, farmers consider fields on the sandy soils more attractive than the finer textured soils in the valley zone in years with water shortage. Yet, this corresponds well to the scientifically proven fact that sandy soils have a higher infiltration capacity and a relatively small proportion of the soil water stored below wilting-point level (Claude et al. 1991).

This possible new trend in landscape specific prioritization that have been specifically exposed through the site specific monitoring of land use sequences is an important issue from an environmental perspective. The cultivation of the sandy soils may well increase their susceptibility to wind erosion if no specific precaution is taken. Monitoring over a longer period will, however, be needed to evaluate the importance of landscape related land use priorities and thereby farmers potential role in causing the degradation process.

Use of land in the Burkinean Sahel

A third example, again from the Sahel, addresses land use alterations at slightly larger spatial scale. The village territory of Yomboli that have been subject to study in this case is located in the northernmost part of Burkina Faso. Rainfall conditions are almost similar to the ones in the Niger example with a yearly rainfall of 300-400 mm. The landscape consists of 4 major landscape elements: a) the pediplain characterized by its hard surface, b) large east-westerly oriented dune bands with coarse, sandy soils, c) the piedmont (transition between dune and pediplain) and d) the border of the mare (Fr. mare = temporary lake) (Figure 5). Farmers in the village cultivate millet and sor-

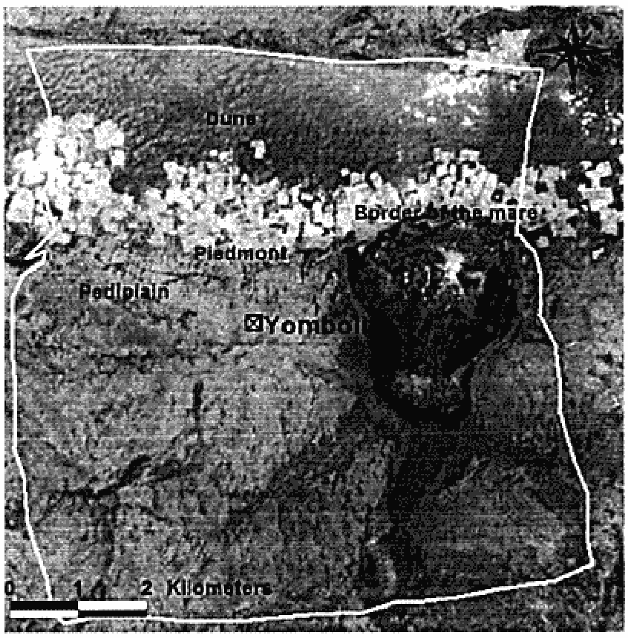

Figure 5: SPOT satellite image of Yomboli village territory. The approximate location of landscape units are indicated. The cultivated areas appear in light grey. From Reenberg et al. (1998).

ghum and some cowpeas and keep livestock that graze in the vicinity of the village territory (Reenberg et al. 1998).

Field history indices

Based on a series of aerial photos and satellite images, the development of the land use, specifically the change in cultivation pattern, has been followed. The geometrically corrected photos and satellite images have been overlayed in a GIS with the aim of tracing the history of individual fields. The time series for the field history has been further prolongated by help of historical information on field location. Locations of fields in the 1940s were identified by local, old informants and recorded in UTM-coordinates corresponding to the corrected images by help of a GPS equipment.

Major changes have occurred in the spatial allocation of fields throughout the period of investigation (1945-1955-1986-1988-1989-1991-1995). As for the Niger example it is important to realize that the impression of an ever expanding area of cultivated land is far too simplistic. The cultivated area has increased three times, but the landscape specific locations of fields have been altered in course of

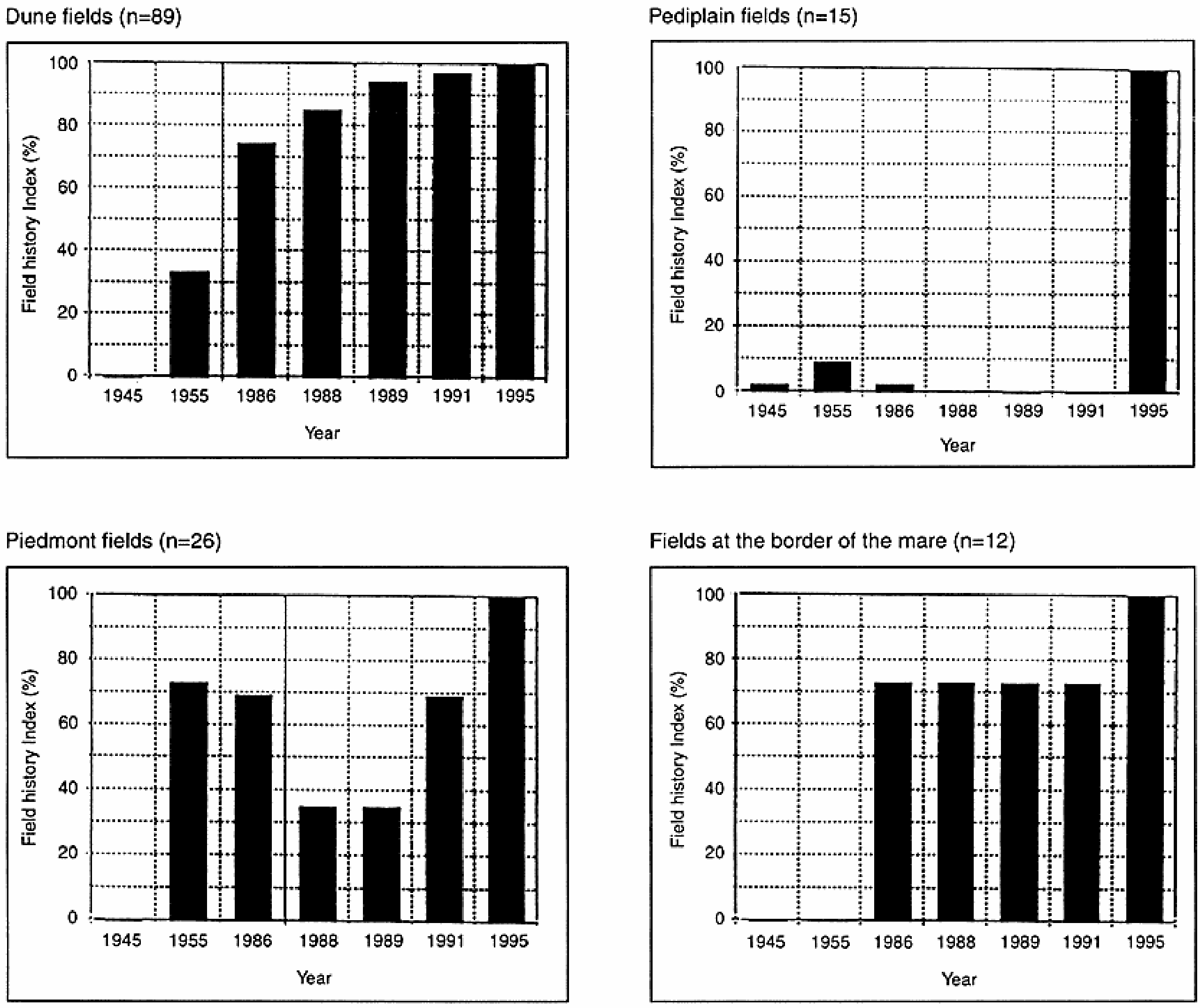

***Figure 6:** The histograms sketch, for each type of landscape unit, the former 'history' of the fields that are presently (1995) cultivated. Each column indicates the percentage of 1995-fields that were recorded as fields the year in question. From Reenberg et al. (1998).*

time as well (see Reenberg et al.1998). At different points in time, different landscape units have been cultivated with different intensity.

A possible way to sketch out typical patterns of land use dynamics that have lead to present land use is offered by the field history index histograms in Figure 6. All fields that are cultivated in 1995 are traced back on the earlier land use maps, and for each year of observation it has been calculated how large a percentage of the 1995 fields that reappears. This percentage, called the field history index (FHI), gives an idea of the trend and stability of the cultivation pattern in the different landscape units, yet, admittedly it is not capable of reflecting micro-rotation between different fields that might occur. Unfortunately, the material collected in for this case does not suffice to a fully-fledged land use sequence analysis along the lines indicated in the Danish example – but even the modified version relying on the field history indices adds considerable to reveal important traits.

Decoding the spatial message

Again, it becomes evident that the picture of cultivated land that gradually expands onto more marginal land at the expense of other land use categories does not suffice to describe the land use alterations. The findings underline how farmers' prioritisation of different landscape units and soil types have changed through time. While the development on the dune conforms well with the picture of a gradual expansion of fields and maintenance of existing ones, this is not true for all landscape units. Fields on the piedmont landscape have been cultivated, abandoned and recultivated. The development in the 1990s reflects farmers' deliberate intentions to diversify their strategies and mitigate potential food deficit due to e.g. rainfall variations. The pediplain has likewise been recultivated in 1995. Thus, the dynamics of field pattern can only be characterized as being spatially complex and with considerable intra landscape units variations.

Quantifying the importance of rotational fallow in southeastern Burkina Faso

A final example deals primarily with land use variations at the micro-scale in time as well as space. The scene is southeastern Burkina Faso in the Soudanian agro-ecological zone. Rainfall is more abundant than in the former cases, yet, water availability is still a constraint to agricultural production in an average year. The agricultural system relies primarily on cropping, with sorghum, rice, groundnuts and cowpeas as the principal crops (Hansen & Reenberg 1998). This part of Africa is frequently reported to be suffering from the environmental stress that arises from increased demographic pressure on land and degradation of soil fertility (e.g. Verlich & Stoop 1990).

Little is, however, known and reported about the precise dynamics of the land use. Statistics are available, but highly unreliable as they are based on very rough estimates. Direct surveys and remote sensing sources of information seem to be the only possible way of obtaining data that can help us to get to grips with the process of land use change.

Many aspects of the changes and their determinants could be of interest. Issues such as land tenure, population pressure, technology, and interactions with other sectors in the society has been dealt with elsewhere (Oksen 1996, Reenberg & Lund 1997, Reenberg 1997). In this context we will confine ourselves to investigate the role of rotational fallow in the agricultural system, an issue which may deserve a more differentiated assessment than frequently seen.

Micro-rotation in land use

In the literature (see e.g. Serpantié 1993) different view exists on the importance of fallow in the Soudano-Sahelian region. In general, the regular alteration between cultiva-

1956		*1956–1972*		*1956–1972–1994*	
C	*8.6%*	*C-C*	*3.6%*	*C-C-C*	*1.5%*
				C-C-NC	*2.1%*
		C-NC	*5.0%*	*C-NC-C*	*1.8%*
				C-NC-NC	*3.2%*
NC	*91.4%*	*NC-C*	*10.3%*	*NC-C-C*	*3.3%*
				NC-C-NC	*7.0%*
		NC-NC	*81.1%*	*NC-NC-C*	*27.3%*
				NC-NC-NC	*53.8%*

C = cultivated, NC = not cultivated.

***Table 1:** Land use sequences corresponding to the maps in Figure 7. The changes between cultivated (C) and non-cultivated (NC) land has been calculated by the GIS in which the land use maps are stored.*

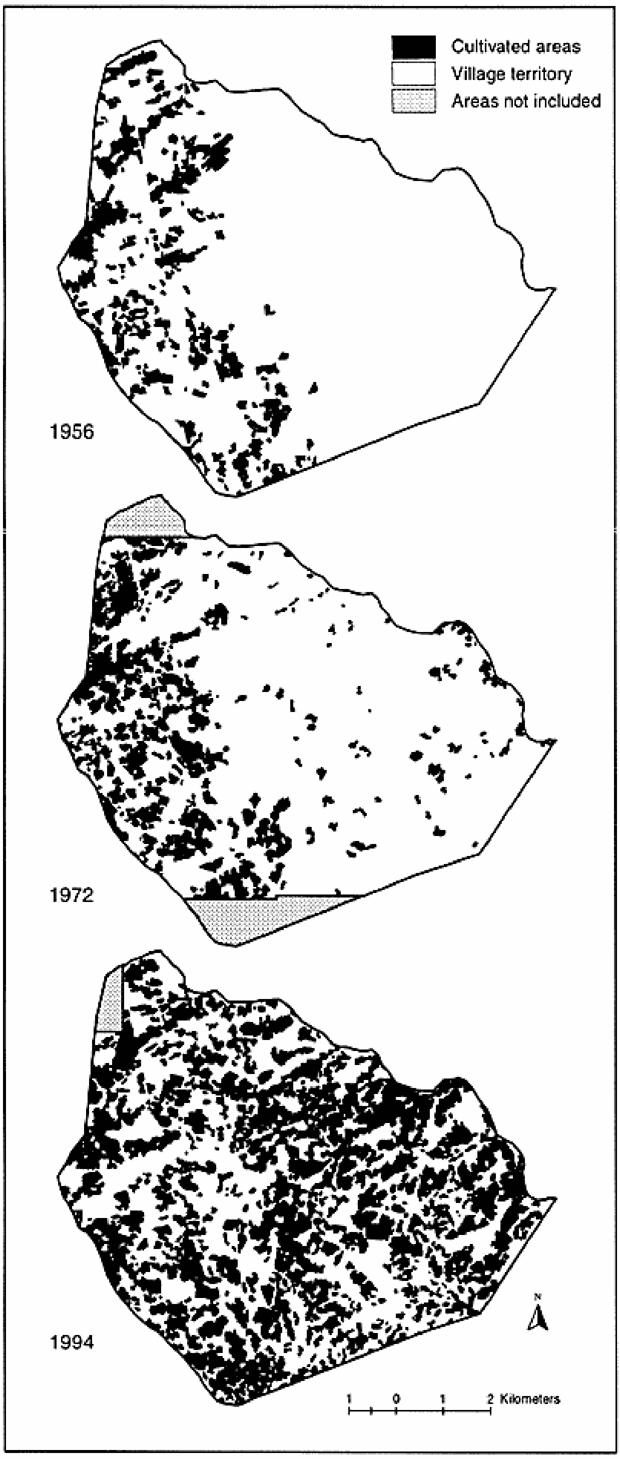

Figure 7: Land use maps from Ningaré village territory, 1956, 1972 and 1994 based on aerial photo interpretation. From Hansen & Reenberg (1998).

tion and fallow that is known from shifting cultivation systems in the more humid tropics is not a characteristic feature of this agro-ecological zone. In the survey conducted in connection with the present case study, farmers often responded negatively to the question whether they had at present fields that were fallowed. One important aim of the land use sequence analysis was thus to take advantage of the georelated information on field pattern that was available through a series of geometrically corrected aerial photos stored in a GIS, with the intention of tracing development patterns.

Figure 7 shows three land use maps from the village territory of Ningaré. They are based on a visual interpretation of aerial photos that are geometrically corrected to UTM-coordinates. This series of land use maps offers the possibility to quantify all possible combinations of land use change patterns as shown in Table 1.

Decoding the spatial message

The figures in Table 1 should be interpreted with some reservation as regards the spatial accuracy because all distortion can not be eliminated through the geometrical correction of the aerial photos (Hansen & Reenberg 1998). However, important trends concerning for example land rotation are shown in the table. A large proportion (>80%) of the land that was cultivated in 1956 was abandoned or fallowed in the years that followed. Also in land use sequence classes representing 'newer' fields, one can observe a significant area that is abandoned (7% in the class NC-C-NC).

Thus, the overall picture is that there certainly is a considerable element of rotation in the use of land. This does not immediately conform with the information gathered through interviews with the farmers. When the farmers do not report that they apply fallow in their agricultural practice, it may be because they do not perceive their land management practice as such. The land rotation is often best characterized as micro-rotations within the land designated to individual farm units (a 'field' in local terminology), and when part of a field is in use, the entire field will be reported as cultivated by the farmer.

Thus, the quantitative registration of land use changes has provided us with figures that enable us to characterize the type and speed of the change process while at the same time serving as a means of adjusting the interpretation of other data sources.

Conclusion

While the examples presented certainly not give an in depth analysis of the individual cases, they may illustrate in which way geographical space can act as 'a marvellous resource allowing new insights from information that might otherwise be regarded as unstructured and unintelligible' (Haggett 1990:68). Thinking spatially does not alone suffice to meet the challenges that the agricultural geography has to address, but it can help to disclose important traits of land use strategies that are otherwise disregarded.

The idea of tracing the use of a specific unit of land through history offers a simple, but efficient means of decoding spatial messages and translating them into important information about the dynamics of the agricultural resource management strategies. Garrity & Augstin (1995) have drawn the attention to the fact that the development of a tool to effectively capture the evolutionary trends in agricultural systems has been neglected. Land use sequence analysis can make a useful contribution in that context, yet, not without skilful combination with other approaches to land use dynamics that enable combination with for example socio-economic factors (Reenberg 1998).

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Conclusion

While the examples presented certainly not give an in depth analysis of the individual cases, they may illustrate in which way geographical space can act as 'a marvellous resource allowing new insights from information that might otherwise be regarded as unstructured and unintelligible' (Haggett 1990:68). Thinking spatially does not alone suffice to meet the challenges that the agricultural geography has to address, but it can help to disclose important traits of land use strategies that are otherwise disregarded.

The idea of tracing the use of a specific unit of land through history offers a simple, but efficient means of decoding spatial messages and translating them into important information about the dynamics of the agricultural resource management strategies. Garrity & Augstin (1995) have drawn the attention to the fact that the development of a tool to effectively capture the evolutionary trends in agricultural systems has been neglected. Land use sequence analysis can make a useful contribution in that context, yet, not without skilful combination with other approaches to land use dynamics that enable combination with for example socio-economic factors (Reenberg 1998).

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