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Spatial and temporal rainfall variability in the Sahel and its effects on farmers' management strategies

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The variability in rainfall in semi-arid Niger is great both spatially and temporally and is considered to be one of the most limiting factors in agriculture. To investigate these constraints more quantitatively, climate data at both survey and detailed scale were analysed. The results show that rainfall can vary considerably even within a few kilometres distance and on different time scales which means that crop yields are very unpredictable. Socio-economic surveys at two villages showed that smallholders have adapted a range of management strategies to ensure at least a minimum yield. Despite this, soil fertility is declining and further technologies need to be integrated into farming systems to make them sustainable.

Keywords: rainfall variability; risk aversion strategies; smallholders; Niger

Introduction

Agro-ecosystems in the Sahelian zone of Niger are characterized by an unfavourable climate and low soil nutrient reserves. Most of the population lives south of the 300–350 mm isohyets, which are regarded as the limit for rainfed agriculture based on pearl millet. Increasing land shortage has forced the farmers to shorten their fallow periods from the traditional average of about 15 years to 2–5 years at present (Wezel, 1998) which leads to a higher land use intensity. This aggravates the problem of nutrient mining and decreases soil productivity. Because manure is limited and the farmers' economic situation enables the application of only small quantities of fertilizer the farmers are not able to balance the nutrient deficits, creating a negative trend in future soil fertility. There is some evidence that the most limiting factors on the sandy soils of semi-arid Niger are the levels of phosphorus and nitrogen rather than water supply (Payne *et al.*, 1991), but other studies on heavy-textured (e.g. Lowenberg-DeBoer *et al.*, 1994) or superficially crusted soils (e.g. Valentin & Casenave, 1992) with low infiltration rates emphasised the increasing importance of water management in drought-prone areas. The negative effect of erratic rainfall on crop yields has been shown both on a nation-wide scale (Ministere de l'Agriculture et de l'Elevage, 1997) and by various field trials (e.g. Bationo *et al.*, 1993). Maintaining productivity and creating options for development are presently the most pressing issues in agricultural research in Niger, however, alternative technologies have to fit into the present bio-physical and socio-economic settings.

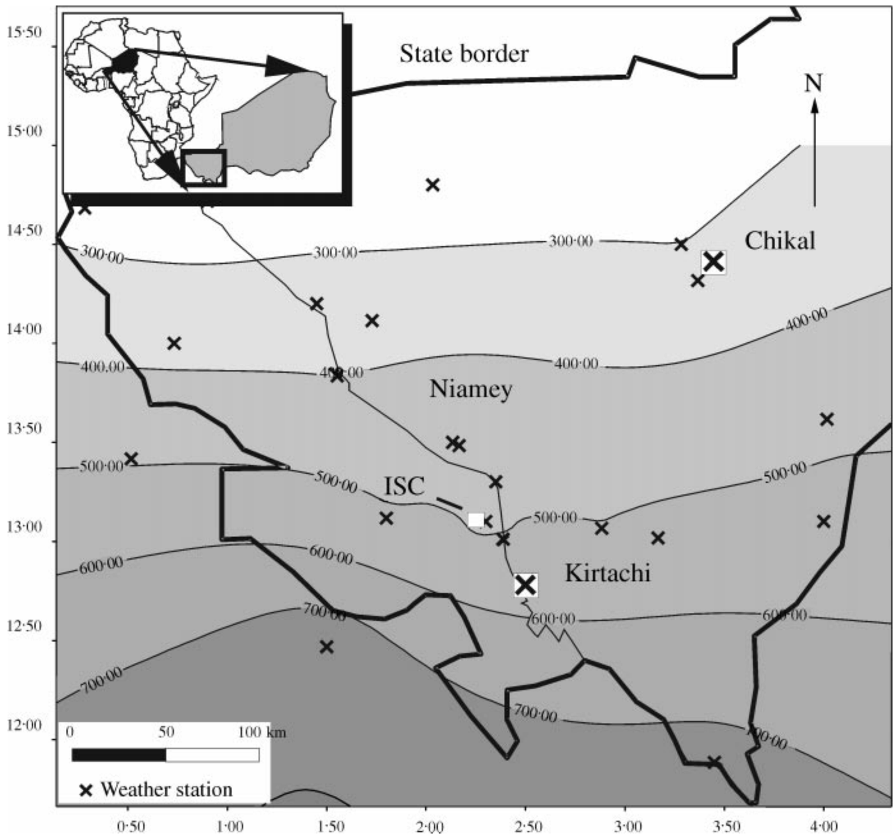


Figure 1. Site locations and isohyets of the average rainfall from 1980 to 1996.

This paper aims at the identification of land use constraints related to temporal and spatial rainfall variability and of strategies developed by farmers to deal with this problem at two climatically different villages, Chical-Chinyassou and Kirtachi-Seybou. Farmer's strategies are identified from an analysis of intensive farm-household surveys. The geographical scope of the study is limited to the agricultural zone of South-west-Niger between the 300 mm and the 800 mm isohyets (Fig. 1).

Methods

The climate database of the FAO (1994) and a geographical information system (GIS) were used to analyse survey level rainfall data. Rainfall at Chical-Chinyassou (Fig. 1) has only been recorded for the last 16 years and at Kirtachi-Seybou only for the last 10 years. Therefore, long-term rainfall data had to be taken from the stations at Filingué and Say, both within a 30-km distance. The rainfall data from 18 rain gauges installed on a 500-ha grid at the ICRISAT Sahelian Centre (ISC) were analysed to determine in detail the spatial and temporal variability of single rain storms (Fig. 2). The rainfall distribution was interpolated with a linear variogram model using the kriging module (Golden Software, 1994) and plotted with contour maps of isohyets. These results were assumed to exemplify conditions at the village of Kirtachi-Seybou. The ISC, Kirtachi-Seybou and Say are situated along a climate gradient of only 50 mm from the driest (ISC) to the wettest (Kirtachi-Seybou) site and can thus be considered comparable in

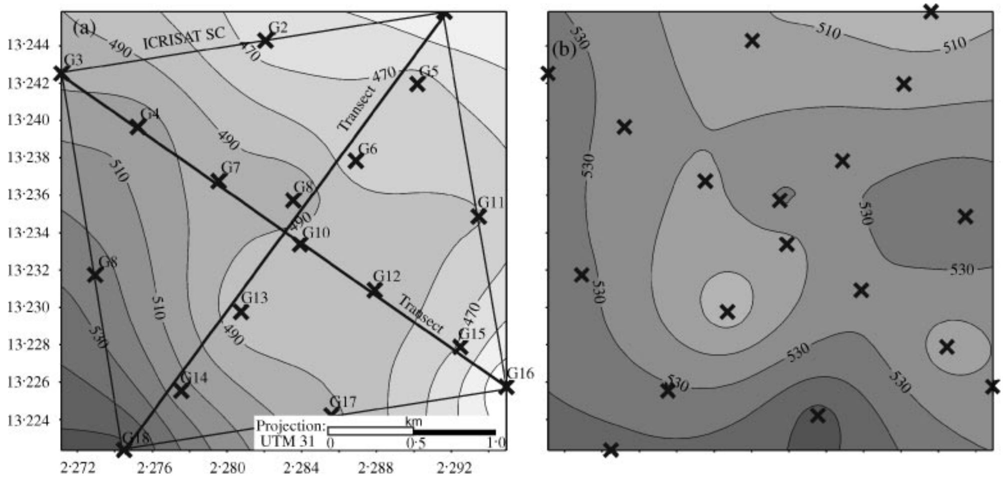


Figure 2. (a) ISC rain gauge positions and (b) spatial rainfall variability in 1995 and 1996.

terms of spatial and temporal variability (Sivakumar *et al.*, 1993). For Chical-Chinyassou no spatial rainfall data were available.

To identify the farmers' field management strategies, detailed socio-economic surveys were carried out at both villages for a total of 42 farmers over a period of three rainy seasons from 1994 and 1996. As well as farm-household characteristics, the survey included data on field management and the delineation of field limits with the help of a GPS (Haigis & Heidhues, 1998).

Study area, rainfall variability at different time scales and farm characteristics in south-west Niger

South-west Niger is covered with wide, often sand-covered pediments and plateaux from various geological substrates. Four categories of soil can be distinguished based on their physical characteristics: deep sandy soils (Arenosols, 40–50%), sand-covered stony or loamy-clayey soils (areni-dystric Cambisols and Acrisols, 20–30%), shallow stony soils (Leptosols, 15–25%) and loamy-clayey soils (15–25%) (Graef, 1999). Deep sandy soils are traditionally cultivated with pearl millet and cowpea, but presently due to land shortage marginal land with shallow soils that after only few years of cropping form surface crusts is also used for cropping or pasture. Most of the area is severely affected by erosion due to extensive cultivation and overgrazing. The vegetation of the study area changes from grass savannah in the north through bush savannah to tree savannah in the south.

The climate of SW Niger is semi-arid with a steep NS-gradient of 300–800 mm rainfall. It is characterized by a high temporal rainfall variability and average monthly minimum and maximum temperatures between 16 and 42°C. A trend towards aridification has been noticed during the last 65 years especially in the more arid regions (Sivakumar *et al.*, 1993). The isohyets have shifted 100–150 km southwards since the 1960s. A close link between the decrease in Sahelian rainfall and the diminution of the number of rainy days (−25%) has been confirmed by Sivakumar (1992), while the average season length and the mean rainfall per event remained constant. The dates of onset and ending of the rains as well as the growing season length has become more erratic, so the timing of cropping has become more risky. The coefficient of variation (CV) for interannual fluctuations in rainfall ranges between 18% in the south and 36% in the north (Le Barbé & Lebel, 1997). Rainfall occurs only during the 3–5 summer months with half the rainy days in July and August and with a very high

Table 1. *Monthly and daily rainfall at Say and Filingué (1961–1990) (Sivakumar* et al., *1993, adapted)*

Month	Mean	S.D.	Max.	Min.	Mean	S.D.	Max.	Min.	Interval
	Rainfall (mm) at Say				Rainy days at Say				
1	0	0	0	0	0	0	0	0	> 30
2	0	0	0	0	0	0	0	0	> 30
3	3	10·8	52	0	0·2	0·6	2	0	> 30
4	7	18·4	98	0	0·6	0·7	2	0	> 30
5	30	27·8	90	0	2·8	2·1	9	0	11
6	94	56·3	270	12	6·5	1·9	10	3	5
7	157	77·2	330	70	8·2	2·0	13	4	4
8	172	64·8	310	47	9·4	2·5	15	5	3
9	97	56·2	260	0	6·5	2·4	12	0	5
10	14	18·6	72	0	1·3	1·4	5	0	23
11	0	0	0	0	0	0	0	0	> 30
12	0	0	0	0	0	0	0	0	> 30
Total	575	137	834	324	35·5	5·3	46	26	—
Month	Rainfall (mm) at Filingué				Rainy days at Filingué				
1	0	0	0	0	0	0	0	0	> 30
2	0	0	0	0	0	0	0	0	> 30
3	0	0	0	0	0	0	0	0	> 30
4	1	2·7	13	0	0·1	0·3	1	0	> 30
5	11	13·6	50	0	1·3	1·3	5	0	23
6	44	26·7	101	2	4·4	1·8	7	1	9
7	114	50·9	218	16	6·8	2·1	11	4	5
8	123	53·4	239	52	8·4	2·3	15	4	4
9	51	36·8	139	0	4·7	1·9	8	0	9
10	4	9·2	35	0	0·4	0·7	3	0	29
11	0	0·7	4	0	0	0·2	1	0	> 30
12	0	0	0	0	0	0	0	0	> 30
Total	348	116	609	135	26·1	5·4	37	15	—

variability. Monthly rainfall analysis for Say (station near Kirachi-Seybou) and Filingué (station near Chical-Chinyassou) indicates a rapid increase of rainfall and rainy days during April–July and a decrease after the peak in August (Table 1). The limitations of this climate on agriculture is shown more clearly by the daily rainfall variability. The average amount of rain per day at Say and Filingué increases during the rainy season and the mean daily maxima are 45 mm day^{-1} and 48 mm day^{-1} in July and August respectively (DMN, 1997). The mean length of time between the rains decreases from 5 to 3 days at Say and from 9 to 4 days at Filingué during the wet season, however, the standard deviation (S.D.) for the mean number of rainy days indicates a high daily rainfall variability. This variability is typical of the Sahelian climate, an observation confirmed by findings at other climate stations in the Sahel. Hourly rainfall intensities from a comparable station at Niono, Mali, exceeded 10 mm h^{-1} for 80%, 25 mm h^{-1} for 65%, 50 mm h^{-1} for 35% and 100 mm h^{-1} for 15% of the events (Hoogmoed & Stroosnijder, 1984), with maximum intensities of 300 mm h^{-1}. High rainfall in so short a time scarcely penetrates the often crusted soils, so a large portion of the rain water is lost by runoff.

Table 2. *Farm-household charcteristics of the study villages (1995)*

	Chical-Chinyassou ($n = 21$)	Kirtachi-Seybou ($n = 21$)
Farm size (ha)	28 ± 14·7*	10 ± 5·8
Farm-field distance (km)	5·7 ± 4·8	1·5 (0·5)
Millet yield (kg ha^{-1})	115 ± 78	572 ± 249
Household size (members)	13·4 ± 6	11·7 ± 6·3
Age of farm chief (years)	54 ± 18	58 ± 11
Main ethnic group	Haussa	Djerma
Value of farm capital (FCFA)†	320,248 ± 289,873	622,949 ± 630,616
Herd size (TLU‡)	4 ± 3·3	4·6 ± 5·1

*Values and standard deviation;
†FCFA: Communauté Financière de l'Afrique Franc or African Financial Community Franc, is the currency for 14 Francophone countries in West and Central Africa. In 1995 1 US$ = 434 FCFA. Farm capital estimation includes farm houses, land, cattle and movables;
‡TLU: Tropical Livestock Unit ATLU is the equivalent of an animal of 250 kg live weight.

Table 2 presents some basic farm-household characteristics, which reflect clearly the differences between Kirtachi-Seybou and Chical-Chinyassou. Although the farms in Chical-Chinyassou are nearly three times larger than in Kirtachi-Seybou, the value of the farm capital, which was used as an indicator of overall prosperity, is almost half that of the farms in Kirtachi-Seybou. This is because millet farming is the main agricultural activity and yields are only a fifth of those in Kirtachi-Seybou. The difference in overall prosperity is lower than that in agricultural productivity, which indicates that non-agricultural income plays a more important role in Chical-Chinyassou than in Kirtachi-Seybou. In Chical-Chinyassou there is no more available land to extend agriculture, whereas in Kirtachi-Seybou there are still some marginal areas, which may be taken into cultivation.

Results

Spatial rainfall variability

The survey scale rainfall data for SW-Niger e.g. for 1989 showed that annual differences of 200–300 mm may occur within a radius of only 100 km. Values for daily rainfall at different stations are only weakly correlated ($r < 0{\cdot}60$ at $p < 0{\cdot}05$), but monthly and annual rainfall correlations tend to be higher ($r < 0{\cdot}80$ at $p < 0{\cdot}05$). This corresponds with (1) findings from Sicot (1991), who could not explain the rainfall dispersion within a 10–15-km radius even though he collected data from 80 rain gauges and with (2) rainfall variograms presented by Amani & Lebel (1997), that exhibit a significant difference within a 10 km distance. This implies that the spatial rainfall variability on a small scale (1 : 1·000–1 : 50·000) is more significant than on the survey level scale (1 : 50·000–1 : 500·000). Most of the fields at Kirtachi-Seybou are located within a radius of 1–5 km from the farm compound (average distance is 1·5 km; Table 2). Therefore the rainfall variability at the detailed (field) scale is of special interest. The ISC data sets of 1995 and 1996 daily rainfall were used to characterise the spatial dispersion of both the annual mean and the daily events (Fig. 2). Over the entire ISC area the rainfall was more homogeneous in 1996 than in 1995. The total rainfall in 1995 varied from 440 to 553 mm within only 2·2 km while in 1996 it ranged from 503 to 554 mm over 0·8 km, which corresponds to maximum gradients of 42 mm km^{-1} and 64 mm km^{-1}

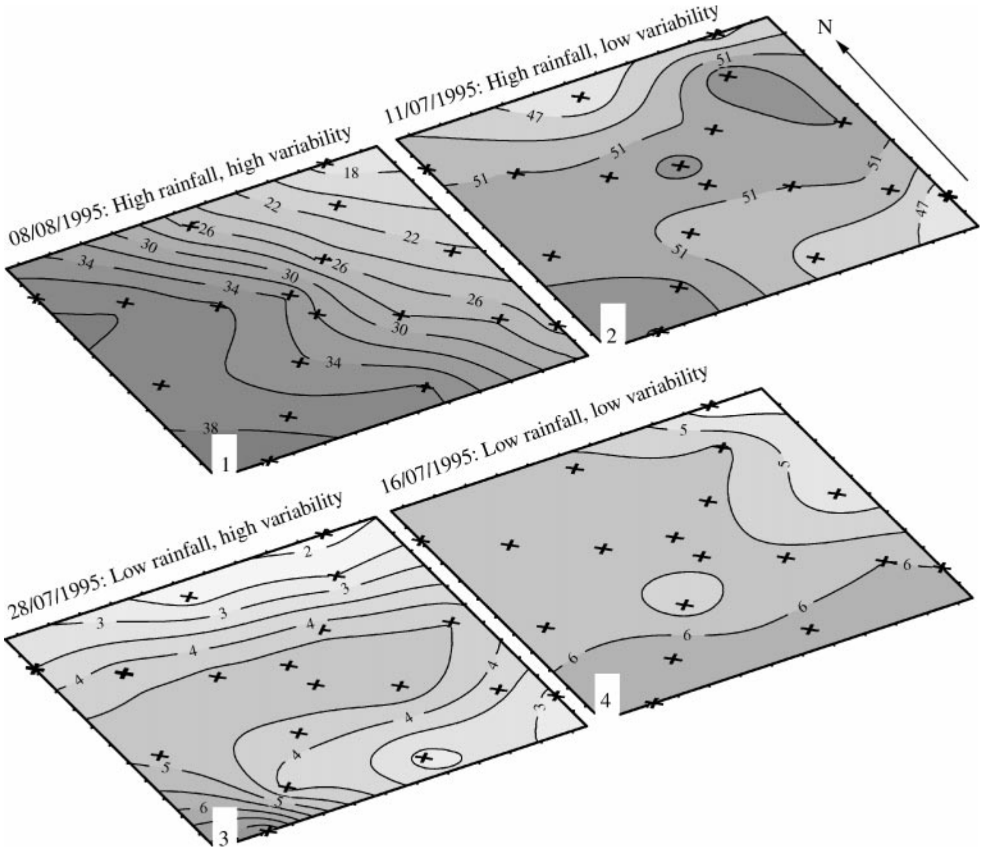
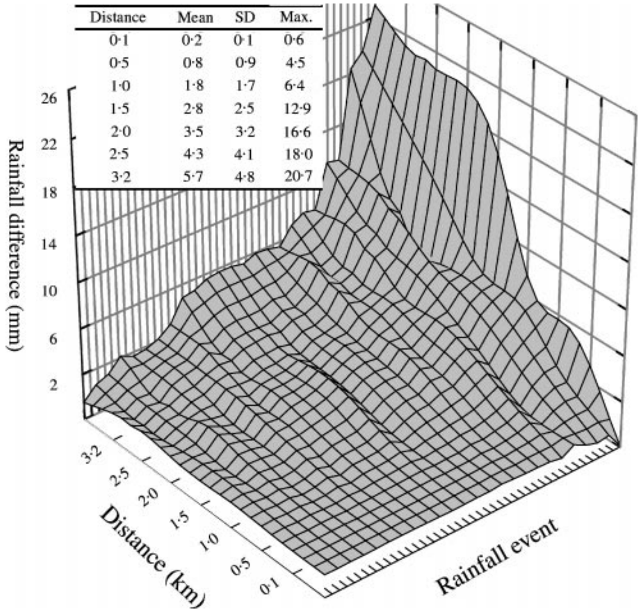


Figure 3. Spatial rainfall variability of selected events at the ISC.

respectively. To reduce the yield losses in bad years it is therefore important for the farmer to cultivate fields at different locations within a few kilometres distance.

Data on selected rainfall events at the ISC (Fig. 3) indicate their variability in terms of intensity and space. The first plot shows a very common situation, a high rainfall event and a distinct rainfall gradient (<17–>40 mm) extending over the ISC with the maximum probably located outside the ISC. The rainfall amount in plot 2 is similar, but the maximum is located within the ISC and there is only a weak gradient (<45–55 mm). Plot 3 shows a low rainfall event with high variability (<2–>8 mm) with the ISC again located within the gradient, maybe at the edge of the rain storm. A very low gradient (<4–>6 mm) is observed for the low rainfall event as shown in plot 4. The amount of rainfall as well as its variability depends on the type of rainstorm and the location within the storm. While the amount of rain in the first two plots is useful to crops, the amounts in the low rainfall events will only infiltrate down to the crop roots if the soil is already moist when the rain starts.

In order to determine and quantify the overall spatial variability of rainfall at the ISC, two cross sections (transects) of 3·2-km length were defined traversing the centre in a NW–SE (G3 to G16) and a NE–SW (G1 to G18) direction (Fig. 2). A total of 80 rainfall profiles were created by taking vertical slices through the daily rainfall contour plots along the transects. Correlations of rainfall amount with increasing distance from the starting points (gauge nos 1 and 3) were calculated. A marked decline in correlation is observed at the most distant gauges, in particular for the NE–SW transect ($r = 0{\cdot}83$



Distance	Mean	SD	Max.
0·1	0·2	0·1	0·6
0·5	0·8	0·9	4·5
1·0	1·8	1·7	6·4
1·5	2·8	2·5	12·9
2·0	3·5	3·2	16·6
2·5	4·3	4·1	18·0
3·2	5·7	4·8	20·7

Figure 4. Analysis of spatial rainfall variability at defined distances at the ISC.

and 0·87 at $p < 0{\cdot}05$ in 1995 and 1996 respectively) compared with the NW–SE transect ($r = 0{\cdot}93$ and 0·89 at $p < 0{\cdot}05$ in 1995 and 1996 respectively). The 1995 rainfall events that exceeded 10 mm (50% of all events) were chosen for a detailed analysis of large scale rainfall variability. They provide at least one third of the water required by the millet crop over a decade (Sivakumar *et al.*, 1993). Also 10 mm is regarded by the farmers as the minimum for exploitable rainfall. The events were profiled along the two transects, analysed statistically and plotted (Fig. 4). The transects were subdivided into seven sections, in order to derive information on rainfall change at seven specific distances from a starting gauge. Since rainfall decline and increase along the two transects were almost equal, they were averaged together. The mean rainfall difference per event ranged from $\pm 1{\cdot}8$ mm at 1 km through $\pm 3{\cdot}5$ mm at 2 km to $\pm 5{\cdot}7$ mm at 3·2 km distance (Fig. 4). It is also remarkable that the standard deviations are as high as the averages and that the maximum differences are four times higher than the averages.

Impact of rainfall variability on farmers' management strategies

The temporal and spatial rainfall variation is of extreme importance to the management both at individual field and at farm level. One prerequisite for good management is the gathering of reliable rainfall and if possible soil moisture information from different locations in the village district. Farmers assiduously observe the weather and regularly check the nearby fields for soil moisture (Altmann, 1997). However, the availability of this information is often limited to a range of a few kilometres. Therefore farmers ask other farmers who cultivate fields further away from the village about rainfall events they have observed or travelling people like herders. Finally, if no news is available about remote fields, they visit the fields concerned regularly around the estimated sowing time.

The farmers have adapted their seeding strategies to the temporal rainfall variability. In former times, farmers planted some portion of their land in advance of the rains while the soil was still dry, a strategy which is called 'dry-seeding'. By dry-seeding all their fields, farmers gain an advantage and avoid labour peaks in the seeding period. Nevertheless this practice does involve the risk of losing the seed in the case of a long dry spell, because high soil temperatures may spoil the seeds. As the temporal rainfall variability increased, the use of this strategy decreased (McCorkle, 1994). Nowadays only a fifth of the farmers in Chical-Chinyassou and none in Kirtachi-Seybou practice dry-seeding. In Kirtachi-Seybou, most farmers wait for the onset of the rain and then check the rainfall amount by testing the soil moisture to a certain depth. However, temporal rainfall variability may force the farmers to resow their fields up to three or four times in drier areas, because germinated plants may die off after a 2-week dry spell. To cope with the annual rainfall variability the farmers use livestock as savings for drought years (LeBel *et al.*, 1996), whereas grain storage is only practised to a minor extent due to store damage.

Since the farmers cannot predict where the rain will fall, they apply two major strategies at the farm level. First, they cultivate fields at different locations within the village district and secondly they tend to sow as much area as possible (McCorkle, 1994). The application of these strategies depends greatly on the distance of the fields from the village, the land use intensity (i.e. availability of suitable land), land tenure and population development. Consequently, both villages show a characteristic scattered pattern of fields, but scattered fields are difficult to seed on schedule. Therefore, the farmers use different maturing varieties in order to distribute labour across a longer period. Small and remote fields especially are sown with early maturing varieties because these are the ones where seeding may be delayed due to labour shortages and problems of access. Nevertheless, scattering of fields and the use of different maturing varieties only reduce the risk of complete production failure. They cannot avoid production losses altogether. In view of both labour shortages and the lack of mechanisation, timely management of fields remains a critical issue for the farmer and it is often observed that some prepared fields are left to fall fallow during the rainy season. For 1995 and 1996 these abandoned areas were estimated at 10–30% in the south (500–800 mm) and 30–80% in the north (300–500 mm).

Strategies to ensure agricultural productivity

Scattering of fields not only creates problems with the farm-labour organisation but also increases the pressure on the available land resources and the cultivation of marginal land. Sowing of all fields reduces both the area under fallow and the fallow period length, which leads to a reduction of soil fertility. The fallow land area, estimated from Landsat TM images of 1992 within a 3-km radius of the villages was only 20–30% for Kirtachi-Seybou and 40–50% for Chical-Chinyassou. Another change which can be observed in the fallow system is that instead of leaving a whole field uncultivated farmers now tend to use the more productive sites within fields, so that they can consist of several parcels with varying fallow or cultivation duration. Hence, other methods preferably with low-input of locally available resources are required to improve the fertility status of the fields. The acceptance and application of these fertilization strategies depend on the ecological conditions (Haigis & Heidhues, 1998).

Various organic materials and inorganic fertilisers are applied using various manuring and mulching techniques to restore the low nutrient reserves (Table 3). On fields close to the village, manure from the farm compound and organic household waste is either placed near the crops or broadcast. Remote fields generally receive less fertiliser. Wealthy farmers have grazing contracts with herders in which they pay the herder with millet to keep the animals entrusted to him for a certain time on a specified field. Millet residues are used to cover those sites within a field, which are infertile or superficially crusted and in Chical-Chinyassou some farmers also add shrub branches which are cut during field preparation. Mineral fertiliser application plays only a minor role in

Table 3. *Fertilisation methods at two villages differing in latitude (1995)*

Fertilization method		Chical-Chinyassou ($n = 21$)	Kirtachi-Seybou ($n = 21$)
Whole-field fallow		33%	33%
Manuring	Grazing contract	38%	62%
	Placed application	29%	67%
Mulching	Broadcast application	5%	5%
	Branches	76%	—
	Millet stalks	100%	100%
Mineral fertiliser		14%	48%

Chical-Chinyassou. At Kirtachi-Seybou almost half of the farms applied mineral fertiliser on millet fields but the amount used (3·4 kg ha^{-1}) was very low. Some of the fertilisation strategies also involve measures such as tree planting to reduce the effects of wind erosion (Sterk & Haigis, 1998).

Discussion

The latitudinal decline in the predictability of crop yield shows, that erratic rainfall is one of the most limiting crop growth factors (e.g. Payne *et al.*, 1991). The analysis of both survey and detailed daily rainfall data indicated that rainfall varied considerably at different spatial (survey scale, field) and temporal (annual, monthly, daily) scales and thus decreased the predictability of crop yields. The erratic rainfall dispersion is caused by irregular movements of weather systems, by sudden southward retreats of the ITCZ, which are common even after rainy seasons have become well established, and by the randomness of the convective cells prevailing in that area, which range over distances of 1–30 km (Goutorbe *et al.*, 1997). The results on spatial rainfall variability obtained at the ISC are applicable to the village of Kirtachi-Seybou, however for Chical-Chinyassou an even higher spatial variability is assumed considering the climate data (Table 1). At Kirtachi-Seybou the rainfall is somewhat more favourable. Severe climate limitations for millet production occur only in one out of eight years and are due to unfavourable rainfall distribution rather than to the total rainfall amount (Graef *et al.*, 1999). In Chical-Chinyassou severe climate limitations occur in one out of three years and often lead to a total loss of millet yield. For the farmer the analysed rainfall data imply that even if there is a quite low rainfall (10 mm) at one field site there is still a high probability of both higher or lower rainfall at another field within a radius of a few kilometres, so the farmer needs information from remote fields. He continuously adapts his management tactics to different rainfall and field site conditions. Considering the spatial and temporal rainfall variability, it is beneficial to the farmer to have some fields dispersed within a radius of a few kilometres. The risk of poor or too intensive rainfall also needs to be considered in the context of differing aspects of terrain, vegetation cover, soil (surface) types and soil management. A high vegetation cover produces low runoff rates. Soil texture and depth influence the moisture content, infiltration rate and the extent of surface crusting which is a determining factor with regard to runoff. Superficially crusted sandy soils even with high internal drainage have a slow surface infiltration (Valentin & Casenave, 1992). Farmers who are used to manage these contrasting conditions generally prefer sandy uncrusted soils for millet cultivation. In some regions of the Sahel traditional water-harvesting techniques exist that concentrate rainfall to areas where water is stored in the soil, such as dams, planting holes and micro-catchments (Tabor, 1995). If properly manured they show promising results especially on crusted soils and for land-poor farmers. However, neither of these techniques are practised in the two villages. Information on dry spells is crucial because some crops or growth stages (e.g. grain filling of millet) are more drought-sensitive than others. The probabilities of different dry spell lengths (Sivakumar *et al.*, 1993) indicate that the number of rain events is most important. Droughts have been recurrent features in the Sahel during the last 90 years. The aim should therefore be to make the present agricultural systems sufficiently flexible to cope with these climate risks within the farmers' traditional setting. Farmers have already developed a range of strategies. Making their own weather and site observations and exchanging local information are a must for the farmer. The strategies involve (1) the time element such as dry-seeding, resowing and the use of different maturing crop varieties; and (2) the spatial planning aspect such as the cultivation of large and widely dispersed fields. Other measures aim at sustaining agricultural productivity in a more general way, e.g. fallows and soil amendments are managed on a very detailed scale within field level. All applied measures depend on various factors such as village-field distance, land use intensity, land tenure and the farmers' socio-economic situation. They enable the farmer to concentrate his activities on specific fields depending on rainfall development during the rainy season and to ensure at least a minimum field production. A total production loss is then unlikely and will only occur in very dry years.

In spite of the crop management strategies outlined above soil fertility is decreasing (Graef, 1999). To obtain long-term stable yields, soil and water conservation techniques (SWC) should therefore be considered, which mitigate the effects of poor spatial and temporal rain distribution, while including the relevant aspects of soil and nutrient conservation (Lowenberg-DeBoer *et al.*, 1994; Tabor, 1995). But these techniques vary greatly as regards both short- and long-term yield and economic benefit. The situation facing Sahelian farmers is urgent so if risk-avoiding techniques are to stand a chance of being adopted they need to be short-term oriented (e.g. ridging, planting in holes, applying moderate amounts of fertiliser or manure), economically viable and in accord with the local agro-ecological and social environment.

Conclusions

Rainfall in SW-Niger varies considerably on both a spatial (survey level and at few kilometres distance) and temporal (annual, monthly, daily, hourly) scale which makes crop yields highly unpredictable. Farmers have therefore developed a range of strategies to cope with rainfall variability depending on site conditions. These strategies include (1) the exchange of information on rainfall; (2) time-dependent measures such as dry-seeding, resowing and the use of different maturing crop varieties, (3) coping with spatial rainfall variability through the cultivation of large and widely dispersed field areas and (4) measures for sustaining soil fertility such as fallowing and the use of soil amendments. This enables the farmer to concentrate the available labour depending on rainfall development and ensures at least a minimum crop production. The application of measures depends on a wide range of ecological and socio-economic factors. The management strategies, which are useful to a wide range of conditions throughout the Sahel, show that farmers are well aware of the limiting ecological factors but the measures are not sufficient to balance the nutrient deficits of the Sahelian soils. For a more sustainable land use, soil and water conservation techniques are therefore recommended.

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