IMPACT OF CLIMATE CHANGE ON AGRICULTURAL PRODUCTION IN THE SAHEL – PART 2. CASE STUDY FOR GROUNDNUT AND COWPEA IN NIGER

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Abstract. During the last 30 years, the climate of the West African Sahel has undergone various changes, especially in terms of rainfall. This has large consequences for the poor-resource farmers depending mainly on rainfed agriculture. This paper investigates the impacts of current climate variability and future climate change on groundnut and cowpea production in Niger for three major agricultural regions, including the groundnut basin.

Niger was one of the largest West African groundnut producing and exporting countries. Groundnut production – as a cash crop – dropped from about 312,000 tons in the mid 1960s (about 68% exported) to as low as 13,000 tons in 1988 and increased again to 110,000 tons in 2000. Cowpea, a food crop, shows a different tendency, going from 4,000 tons in the mid fifties to a maximum of 775,000 tons in 1997, and its cultivated area is still increasing. It is also a cash crop in local economies (especially for women).

To highlight the impact of climate change on groundnut and cowpea production (significantly determined by rainfall in July, August and September), the following components of the rainfall regime were calculated for the period 1951–1998: mean annual and monthly rainfall, beginning, end and length of the rainy season, number of rainy days per month, amount of rainfall per rainy day and the maximum length of dry spell per month. Three sub-periods whose duration varied per region were defined: for Dosso 1951–1968, 1969–1984 and 1985–1998; for Maradi 1951–1970, 1971–1987 and 1988–1998; and for Zinder 1951–1966, 1967–1984 and 1985–1998. A change in rainfall regime components was observed between the three sub-periods, which were characterized in chronological order by wet, dry and intermediate conditions.

To assess the impact of climate variability and change on groundnut and cowpea production, a statistical modeling approach has been followed, based on thirteen predictors as described and discussed in the preceding paper. Climate change is mimicked in terms of reduced total amount of rainfall for the three main rainfall months and an increased temperature, while maintaining other significant predictors at a constant level. In 2025, production of groundnut is estimated to be between 11 and 25% lower, while cowpea yield will fall maximally 30%. Various strategies to compensate this potential loss are presented for the two crops.

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1. Introduction

The climate of the West African Sahel is characterized by highly variable rainfall in both time and space, details being presented in the preceding paper (Ben Mohamed et al., 2002). Despite these variable and irregular climatic conditions, Niger was a large producer of groundnut (*Arachis hypogeae* [L.]) in West Africa in the 1960s (production about 312,000 tons of which about 68% was exported) in West Africa. Groundnut production fell, however, due to various factors. These include: ecological (e.g., reduced rainfall, occurrence of rosette disease, soil degradation), technical (limited amounts of agricultural inputs, seeds and farming techniques), socio-economic (e.g., lack of motivation of farmers due to the downward trend of groundnut prices and the share going to the producer being very small; reduced or irregular fertilizer availability), political and economic (a reduction in groundnut price on the world market trend relative to soybean and sunflower since 1978) (Gillier, 1984; Giri, 1983), but their relative contribution is unknown. At present, because of current low groundnut productions, Niger has even become a major importer of vegetable oil.

Cowpea (*Vigna unguiculata* [L.] Walp.) is now the main legume food in Niger. It is better adapted than groundnut to relatively dry conditions and poor soils. Its importance as a cash crop increased, especially in local economies. The decline in groundnut production and the development of cowpea cultivation coincided with the two recent great droughts (1972–1973 and 1983–1984) that had dramatic effects on agricultural production. In 2000 Niger's total cowpea production of 650,000 tons was almost six times higher than that of groundnut (www.fao.org).

Overall, both crops are important to Niger and its farmers because (i) as a cash crop their exports constitute an important source of foreign exchange, (ii) they provide a food source due to their very high nutritive value (especially proteins) both for humans and animals and (iii) from an agronomic point of view, as leguminous species, they enrich the soil with nitrogen.

Following the preceding paper on the methodological approach and the case study on impact of climate change on millet production (Ben Mohamed et al., 2002), this paper will discuss the impact of current climate variability and future climate change on groundnut and cowpea production. Details are also included for impact of droughts in the course of the growing season.

1.1. GROUNDNUT AND COWPEA IN NIGER

Groundnut was introduced in West Africa around 1850 and in Niger towards the end of the 19th century. In Niger, groundnut farming experienced a remarkable development between 1950 and 1970, with a period of increased production in the 1960s due to a rapid increase in land areas and yield (Table I). This was followed in the seventies and eighties by a real slump in production and exports to such a

Table I
Stages in the evolution of groundnut production in Niger

End of the 19th century: introduction of groundnut into Niger: cultivation was undeveloped because of the landlocked conditions and no transport infrastructure.	
1908	Construction of the Kano (Nigeria) railway: development of groundnut in the eastern and central parts of Niger.
1924	Exports reached 1,500 tons.
1938	Exports increased to 13,700 tons.
1942	Creation of 'Société Industrielle et Commerciale du Niger' (SICONIGER).
1938–45	Slowdown of production due to the war.
1950s	Increase of production from 76,000 tons in 1953 to 193,000 tons in 1957.
1957	Establishment of the 'Société des Huileries du Niger (SHN)', and the 'Société Industrielle et Alimentaire de Magaria (SIAM)'.
1960	Production level at 150,000 tons.
1962	Closing down of SIAM, and establishment of the 'Société Nigérienne de Commercialisation de l'Arachide (SONARA)'.
1965–70	Export of groundnut products accounted for 65–72% of the total export of the country.
1966	Record production of 311,900 tons.
1967	Record level of land areas sown with cereals being 432,000 ha.
1972	Start of Project 'Revival of Groundnut Cultivation'; production level at 260,000 tons.
1972–89	Decline in groundnut production (land areas reduced by 50% and production by 80% between 1960 and 1984).
1975	Destruction of groundnut production by rosette disease.
1987	End of project workshop 'Revival of groundnut cultivation'.
1989	Closing down of SONARA.
1990–96	Renewed increase both in terms of land areas cultivated reaching in 1996 416,000 ha and a production of 196,000 tons (i.e., 10 times that of 1990) and development of small scale groundnut processing units, strengthened by an improvement in Niger's competitiveness following the devaluation of the CFA franc.
2000	250,000 ha harvested and 110,000 tons production (www.fao.org).

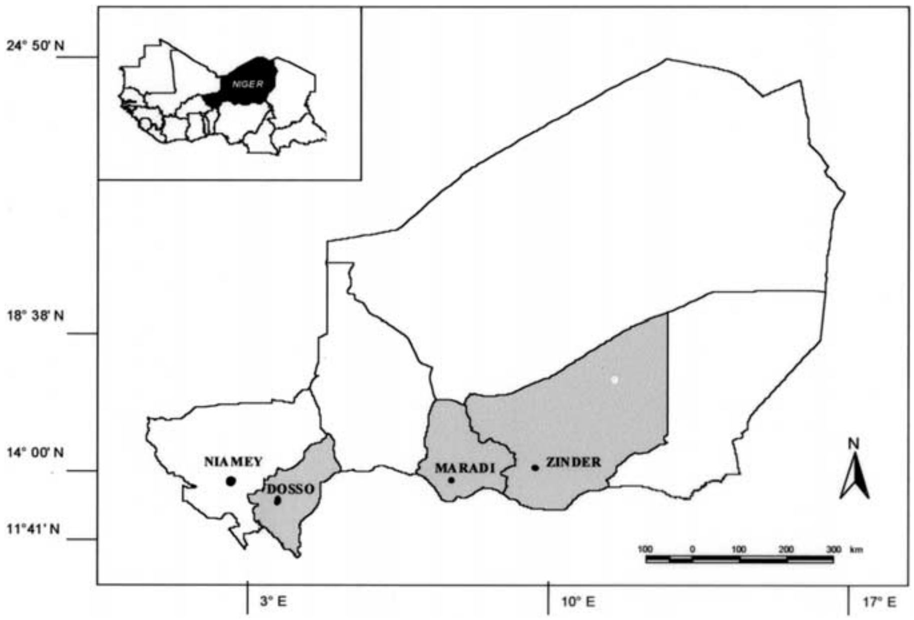

Figure 1. The major groundnut and cowpea producing regions in Niger.

point that groundnut became a crop mostly processed traditionally into vegetable oil and oil-cakes for local consumption (Toukoua, 1986).

Groundnut is grown south of 15° N. The most important producing area, formerly called the 'groundnut basin' is situated mainly in the regions of Dosso (31,000 km^2), Maradi (38,580 km^2) and Zinder (145,430 km^2). This area is situated in the southern part of the country in a band (stretching from west to east) along Nigeria's northern border with a fringe about 100 km wide (Figure 1). Zinder and Maradi regions accounted for the bulk of national production, i.e., 45–60% and 30–45%, respectively (Gillier and Silvestre, 1969). Since groundnut's water requirements are related to the variety, short-cycle varieties (90 days) are cultivated in the north of Niger (< 500 mm), medium-cycle varieties (105 days) in the center (rainfall between 500 and 600 mm) and long-cycle varieties (120 days) in the southern part where annual rainfall exceeds 600 mm (Oumarou et al., 1990). The southwards shifting of isohyets (Ben Mohamed et al., 2002) led to a reduced groundnut farming zone due to the inadaptability of the varieties to water deficits. At present, Niger produces only about 2% of the total groundnut production in West Africa (2000; www.fao.org).

Cowpea is grown between 350 and 900 mm isohyets and is often intercropped with millet. After the fall in groundnut production, cowpea became Niger's second and third most important crop of the country, in terms of cultivated area and production respectively (Adam, 1989), as illustrated in Figure 2. Like groundnut, the main cowpea cultivation zones are the Dosso, Maradi and Zinder regions, which

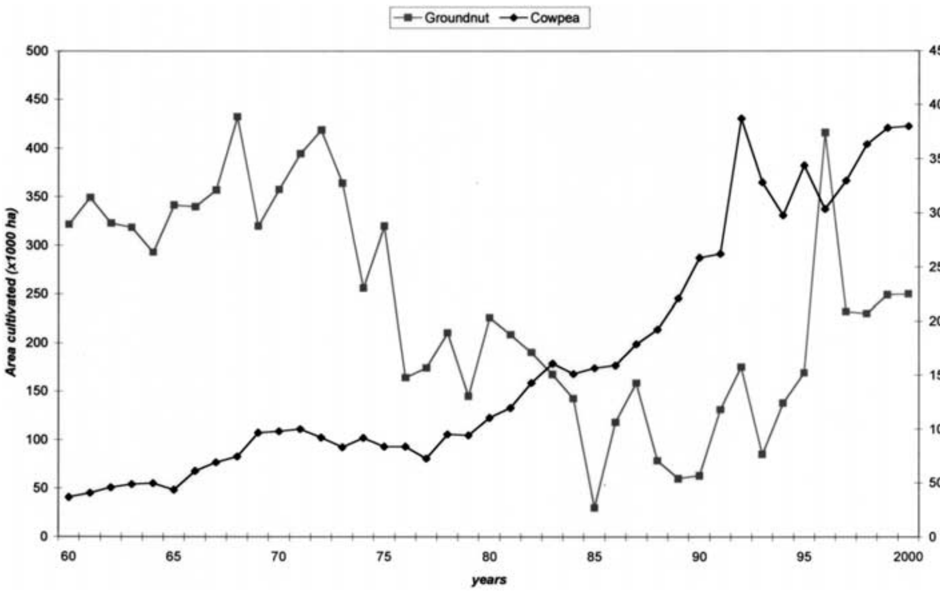

Figure 2. Variation in groundnut and cowpea cultivated area in Niger (Ministère de l'agriculture and www.fao.org (1996–2000)).

account for about 65% of the total cultivated area and national production. Niger is the second largest cowpea producer in West Africa with 22% of the total in 2000 (Nigeria produces 72%; www.fao.org).

Both crops are sensitive to water shortage during certain growth stages and its effect depends on the timing, its duration and intensity, i.e., the degree of evaporative demand. The importance of the timing of drought has still not been completely quantified. Ndunguru et al. (1995) have found that late-season drought has the largest impact, while Pallas et al. (1979), Williams et al. (1986) and Nageswara Rao et al. (1985) have found that end-of-season droughts (pod-filling stage) result in poor yields. We agree with the latter group, and in this study we consider the pod-filling phase as the most sensitive to drought.

2. Methodology

The methodological approach used in this study has been described and discussed in the preceding paper (Ben Mohamed et al., 2002). Likewise, the focus of this study is on a major producing area, the old groundnut basin, comprising the Dosso, Maradi and Zinder regions (Figure 1).

To study the climate inter-annual variability in more detail, the rainfall regime components were considered (cf. Sivakumar et al., 1993). These included: annual rainfall average, monthly rainfall averages of July, August and September, rainfall amount per rainy day, number of rainy days per month, maximum length of dry spells (i.e., the number of days without rain) in each month and the beginning, the end and the length of the rainy season (LRS). The starting date of the rains (Sr) is defined as the day after 1st May when rainfall received in one or three consecutive days equals or exceeds 20 mm and when no period of drought of more than seven days intervenes in the following 30 days. The date of end of the rains (Er) corresponds to a date after 1st September with rain and thereafter rainfall of less than 5 mm for a period of 20 days. LRS is the number of days between Sr and Er. The relevant dates have been calculated using INSTAT (Stern et al., 1996) and SAISON Software (ICRISAT-Niamey, unpublished). Although spatial variability in rainfall is very high, due to absence of a sufficiently dense matrix of rainfall gauges within a region, we base our analysis on the data of the main meteorological stations of the region (i.e., Dosso, Maradi and Zinder) which we consider representative.

In addition, region specific sub-periods are defined to explain, from a climate point of view, the bio-physical reasons for the decline in groundnut production after a period of abundant production. They are based on the five-year moving average and annual rainfall variation curves as compared to the long-term average. The end of a sub-period is defined as when rainfall is below the long-term average for more than two consecutive years.

Finally, to analyze the availability of sufficient water during pod filling in view of a possible change in climate, the rainfall regime components for the three main rainfall months (July, August and September) were investigated. During these months about 85% of the annual rainfall is received (Sivakumar et al., 1993).

3. Results and Discussion

3.1. CLIMATE VARIABILITY BY RAINFALL COMPONENTS

3.1.1. *Annual Rainfall*

Like for the average annual rainfall for Niger (Ben Mohamed et al., 2002), three sub-periods (SP) were defined for each region (Table II). The first sub-period (SP1) extends from 1953 to the end of the 1960s with rainfall exceeding the long-term average (1951–1998) and an upward trend for all the locations studied. During SP1, groundnut production was abundant, in contrast to cowpea. The end of this period varies per region: in 1966 in Zinder, 1968 in Dosso and 1970 in Maradi. The low standard deviation (lower than for the two others) also indicates a better inter-annual rainfall distribution for all regions. Rainfall during SP2 is below the long-term average, and a clear downward trend to the end of the 80s for all locations was observed. It was noted, however, that in Zinder, this trend continued until in the mid-90s (Figure 3). SP2 is characterized by two severe droughts (1972–1973 and 1983–1984) with a slight improvement of annual rainfall in between. Droughts occurred in the periods of 1969–1974 and 1980–1984 in Dosso, 1971–1975 and

Table II

Average rainfall, onset, end and length of rainy season for the entire period and per sub-period (SP) for the three regions in Niger

Parameters	Long term values (1951–1998)	Sub-period		
		SP1	SP2	SP3
Dosso		*1951–1968*	*1969–1984*	*1985–1998*
Annual rainfall (mm)	578 ± 143	663 ± 95	473 ± 138	569 ± 132
Onset of rain	19 June ± 16	17 June ± 18	18 June ± 18	19 June ± 11
End of rain	2 Oct. ± 11	9 Oct. ± 7	23 Sept. ± 8	30 Sept. ± 11
Length of season	106 ± 20	115 ± 20	98 ± 21	104 ± 17
Maradi		*1951–1970*	*1971–1987*	*1988–1998*
Annual rainfall (mm)	520 ± 131	613 ± 92	413 ± 111	501 ± 88
Onset of rain	27 June ± 25	19 June ± 29	30 June ± 23	27 June ± 25
End of rain	2 Oct. ± 11	4 Oct. ± 11	25 Sept. ± 7	4 Oct. ± 11
Length of season	98 ± 27	108 ± 29	89 ± 22	100 ± 21
Zinder		*1951–1966*	*1967–1984*	*1985–1998*
Annual rainfall (mm)	434 ± 130	542 ± 95	391 ± 111	367 ± 110
Onset of rain	9 July ± 18	28 June ± 16	8 July ± 16	16 July ± 16
End of rain	26 Sept. ± 10	27 Sept. ± 10	26 Sept. ± 10	27 Sept. ± 11
Length of season	82 ± 22	92 ± 20	81 ± 19	74 ± 20

1981–1987 in Maradi and starting from 1967 in Zinder. During SP2, groundnut production reduced considerably. SP3, starting in the mid-1980s, shows higher values (but still less than during SP1), especially in Dosso (since 1985) and Maradi (since 1988).

3.1.2. *Beginning and End of Rains*

Concerning the beginning and end of the rains, Table II shows a delay in the onset and an early end of rains during SP2. The delay in Dosso, Maradi and Zinder is 1, 11 and 12 days, respectively, while the end in Dosso and Maradi occurs 16 and 9 days earlier. The end-of-season in Zinder does not vary among the sub-periods.

3.1.3. *Length of Rainy Season*

As a consequence of the shift in the beginning and end of the rainy season among the sub-periods, the length of the rainy season (LRS) varied strongly in all locations. From SP1 to SP2, LRS reduced by 12 (Zinder) to 19 days (Maradi); Table II. During the droughts of 1969–1974 and 1980–1984 in Dosso, LRS decreased by 22 and 25 days, respectively. In Maradi and Zinder, even higher reductions

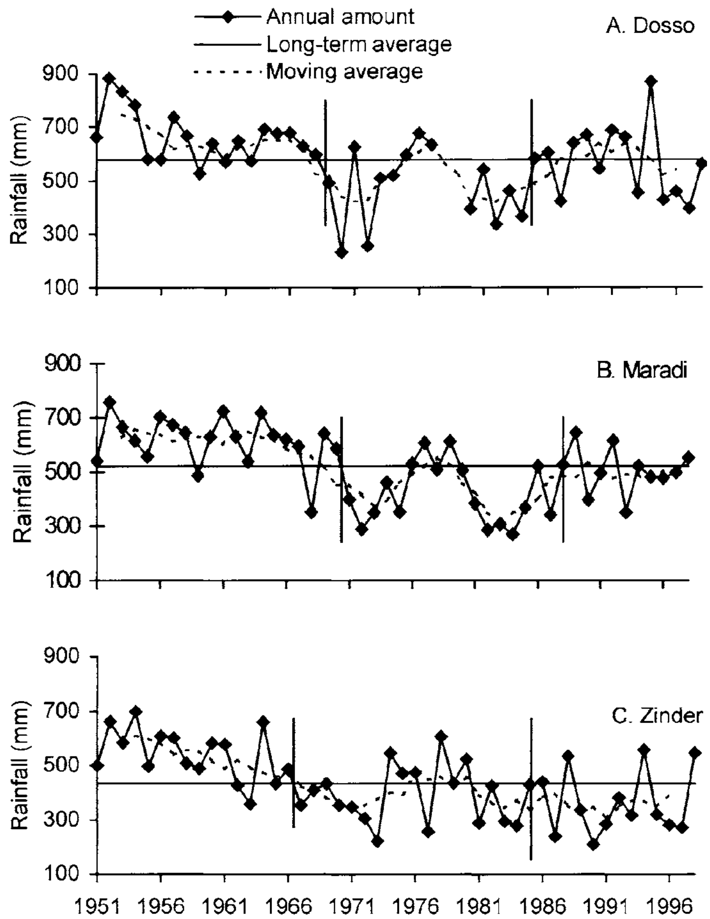

Figure 3. Observed (solid line) total annual rainfall, its moving average (dotted line) and long-term average (horizontal line) for the three sub-periods (divided by vertical line) for the three regions in Niger. A: Dosso, B: Maradi and C: Zinder.

were observed (Maradi: 40 and 26 days for 1971–1975 and 1981–1987, respectively; Zinder: 31 days for 1967–1973). This reduction in LRS had considerable consequences on groundnut production, as growth cycles of crops could not be completed.

3.1.4. *Monthly Rainfall*

All locations showed a decreasing amount of rainfall for the months July, August and September as illustrated for Maradi (Figure 4), although the trend in July was not that clear. In addition, a drop in the curve of the moving averages from the 1990s for all the locations has been observed. The three months covering the vegetative period were characterized by excess rainfall for all locations in SP1

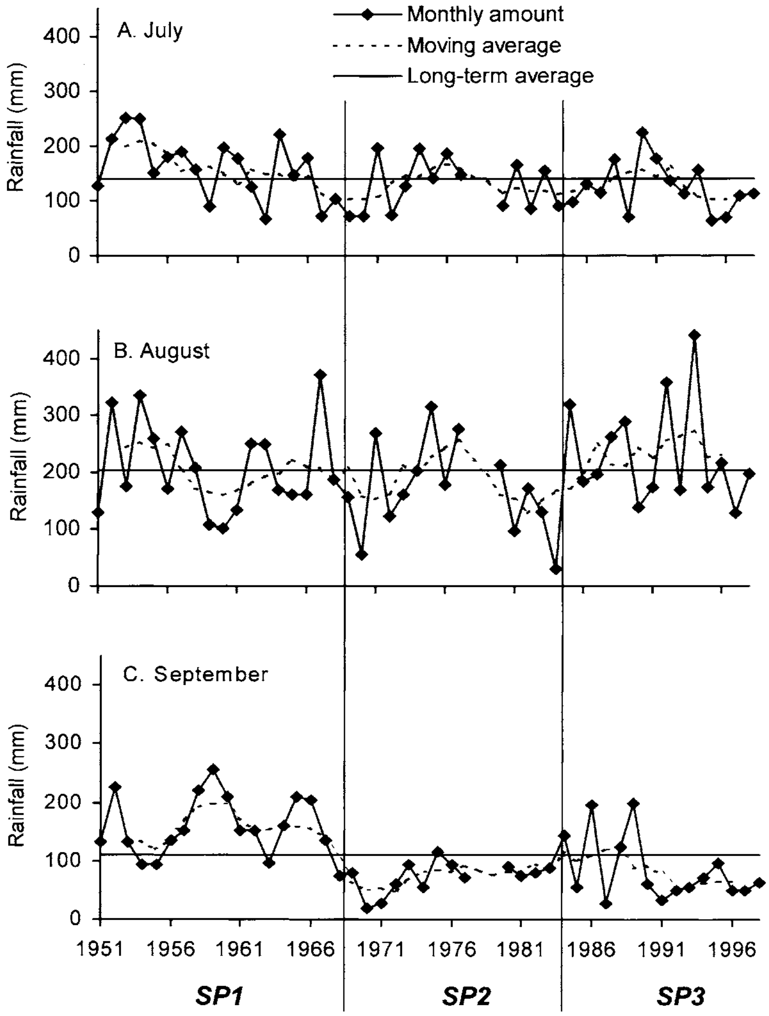

Figure 4. Observed (solid line) monthly rainfall, its moving average (dotted line) and long-term average (horizontal line) for the three sub-periods (divided by vertical line) for the three months at Maradi in Niger. A: July, B: August and C: September.

(Figure 5) with September being a 'wet' month. These are favorable conditions that may explain the good groundnut production during this sub-period.

3.1.5. *Number of Rainy Days per Month and Amount of Rainfall per Rainy Day*

The number of rainy days per month did not vary much between the sub-periods. In contrast, the variation of the amount of rainfall per rainy day was quite remarkable (Table III). In July, the number of rainy days remained the same for all regions. However, the dry sub-period of each region showed a very low amount of rainfall per rainy day as compared to the average. August was characterized by very low

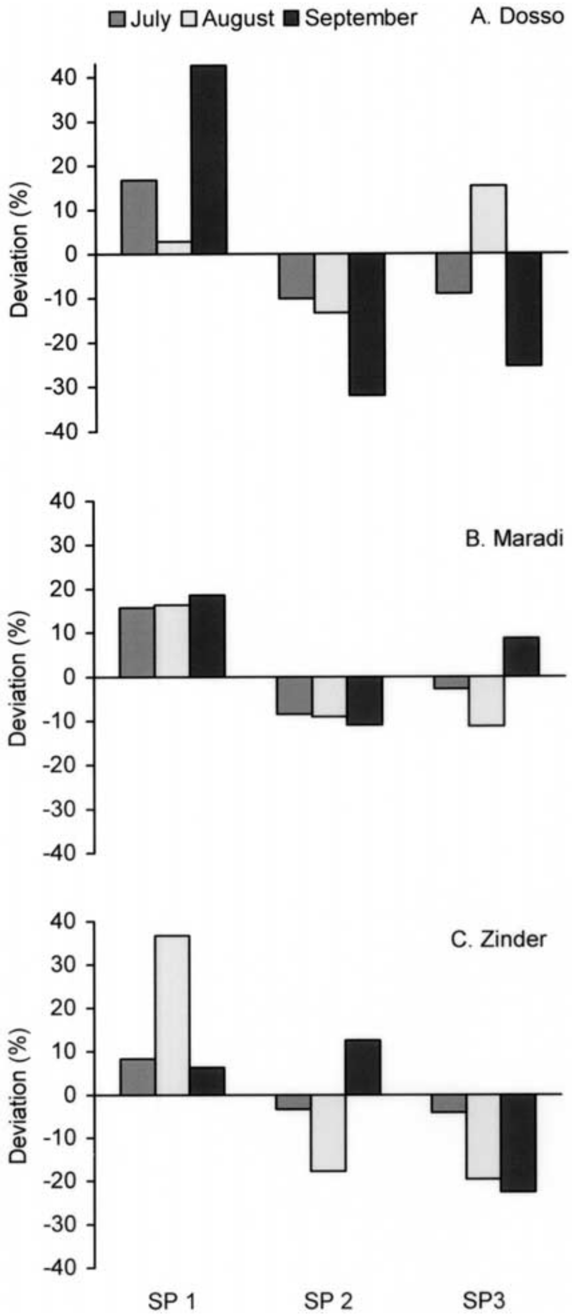

Figure 5. Deviation from average monthly rainfall (%) for the three sub-periods (SP1-3) for the three regions in Niger.

Table III

Average number of rainy days per month (Rd/m), and average amount of rain per rainy day (R/Rd in mm) for the entire period and per sub-period in the three main months of the rainy season for the three regions in Niger

Region	Period or sub-period	July		August		September	
		Rd/m	R/Rd	Rd/m	R/Rd	Rd/m	R/Rd
Dosso	*1951–98*	*8.7*	*15.7*	*11.1*	*18.1*	*7.9*	*13.4*
	1951–68	9.3	17.5	12.1	17.5	10.2	15.9
	1969–84	8.2	13.9	9.2	16.9	6.0	11.0
	1985–98	8.4	15.1	11.6	19.9	6.5	12.1
Maradi	*1951–98*	*10.4*	*11.7*	*14.0*	*13.6*	*10.1*	*10.5*
	1951–70	11.7	11.7	14.5	15.0	11.7	11.8
	1971–87	10.1	10.4	13.8	12.1	7.6	8.2
	1988–98	8.6	13.6	13.3	13.5	10.9	11.7
Zinder	*1951–98*	*10.8*	*11.1*	*12.5*	*13.3*	*8.6*	*9.0*
	1951–66	11.5	11.3	14.6	15.6	9.1	9.0
	1967–84	10.7	11.0	11.2	12.6	9.2	10.3
	1985–98	10.1	11.0	11.8	11.7	7.3	7.6

variations in average rainfall amount per rainy day as well as in the number of rainy days per month. In Maradi and Dosso, the amount of rainfall per rainy day September showed the lowest value in SP2. In contrast in Zinder, during SP3 this number of rainy days as well as the amount of rainfall per rainy days reduced considerably (Table III).

In the Sahel, in general, 85% of rainfall originates from squall lines, i.e., as convective precipitation (Saloum, 1992). From a general meteorological viewpoint, the strength of the synoptic scale disturbance line (easterly waves) and its associated parameter the vertical upward motion, fully determine the abundance of convective precipitation in this area. This highlights the importance of scale interaction in the production of rainfall in the Sahel. Both SP2 and SP3 were characterized by occurrence of the strongest El Niño events of the century and, as already shown in the preceding paper (Ben Mohamed et al., 2002), rainfall in the study area has the highest correlation with sea surface temperatures of the Niño3 Region. This observed phenomenon has clearly associated reducing effects on the chances of fruitful groundnut cultivation during these sub-periods. Moreover it forces farmers to reduce their area with groundnut, as witnessed by the fall in area harvested from 1996 to 2000 (Table I).

Table IV

Monthly mean maximum dry spells (DSL, in d) and percentage of years with dry spells more than or equal to 7 days per month (YDS, in %) for the three sub-periods per region in Niger

Region	Sub-period	July		August		September	
		DSL	YDS	DSL	YSD	DSL	YDS
Dosso	1951–68	6.3 ± 2.0	33	6.4 ± 2.7	28	5.6 ± 1.8	28
	1969–84	7.0 ± 2.5	57	7.4 ± 2.7	64	10.0 ± 2.9	92
	1985–98	9.1 ± 3.5	92	5.8 ± 2.2	23	10.1 ± 4.4	93
Maradi	1951–70	6.9 ± 2.2	45	5.8 ± 1.6	30	7.2 ± 2.8	60
	1971–87	10.2 ± 4.2	76	7.1 ± 2.0	47	10.3 ± 4.4	88
	1988–98	9.5 ± 3.5	82	6.2 ± 2.8	36	7.9 ± 3.5	73
Zinder	1951–66	7.0 ± 1.6	50	5.9 ± 2.4	31	8.4 ± 2.5	69
	1967–84	8.6 ± 2.6	71	7.8 ± 2.8	67	9.5 ± 2.8	82
	1985–98	8.4 ± 3.1	64	6.1 ± 1.4	29	12.3 ± 5.2	86

3.1.6. *Maximum Dry Spells per Month*

The average maximum dry spell length (DSL), as well as the percentage of years with dry spells more than or equal to 7 days (YDS) were lower in SP1 than in the other sub-periods in all regions and for all months, except for Dosso in August (Table IV). In SP2, both DSL and YDS were much larger for all regions, while during SP3 this fell again in Maradi, while in Dosso and Zinder this reduction occurred only in August. For the latter two regions the other months showed mixed patterns. Depending on their length and the vegetative stage during which dry spells occur, they affect largely agricultural production particularly in the Sahel, where the soil dries up after a few days without rain due to the high evaporation rates (Wallace, 1991).

3.2. CLIMATE INDUCED CONSTRAINTS TO GROUNDNUT AND COWPEA PRODUCTION

The three sub-periods mentioned above correspond in chronological order for all regions to periods of good, largely reduced and a revived groundnut production. The analysis above also shows that the beginning of the decline in groundnut production only started some years later than the decline in rainfall. For instance, the decline in annual rainfall started in 1968, but only in 1973 did a reduction in arable land areas and groundnut production became clear. During and after SP2, however, cowpea production increased (Figure 2).

Table V

Land area of Niger (% of total) in agro-ecological zones based on annual rainfall (mm) and on length of growing period (LPG) in the last five decades

	1951–69	1969–87	1988–98	1969–98
Rainfall				
< 300	73.2	85.1	82.6	84.5
300–400	10.2	8.8	7.6	8.0
400–500	6.4	4.0	5.7	4.8
500–600	6.0	1.5	2.5	1.8
600–700	3.0	0.5	1.3	0.7
> 700	1.2	0.1	0.3	0.2
LPG				
< 70	70.1	84.2	79.0	81.1
70–90	16.4	10.3	12.5	12.1
90–110	10.7	3.8	5.7	5.1
110–130	2.6	0.2	2.5	1.6
> 130	0.2	1.5	0.3	0.1

The direct impact of the change in climatic conditions during the period of investigation resulted in a reduced groundnut-cultivated area because of the southward movement of isohyets (Ben Mohamed et al., 2002) that excluded villages which were previously large producers. Secondly, the reduced length of the vegetative period no longer allows the present varieties to complete their cycle. Reduction in the number of rainy days per month and the rainfall amount per rainy day, as well as the increase in the length and frequency of dry spells are additional biophysical factors that contributed to the sharp fall in groundnut production. Other factors include the chronic shortage of groundnut seeds, due to a succession of years of deficit rainfalls. Finally, since the climate change did indeed affect all rainfed agriculture, farmers opted thereafter for the cultivation of food crops to satisfy their needs at the expense of groundnut cultivation (Giri, 1983) and for cowpea as a food and cash crop. Table V also illustrates the increase in Niger's area subject to climate risk (< 400 mm or LGP < 90 days) from 1951–1969 to 1969–1987, which slightly reduced thereafter, but the area still being higher than that in the period 1951–1969.

3.3. Potential Impacts of Future Climate Change on Groundnut and Cowpea Production

From the preceding section it is evident that a further change in climate will affect the production of groundnut and cowpea. Using the statistical model (Ben Mohamed et al., 2002), the results (presented as a temporal evolution of parameters observed and estimated) for the two crops in the three regions are presented in Figure 6.

Table VI presents the summary of the ANOVA results and the models' performances. The obtained models show probabilities of detection of the production categories well above 60% and a very low false alarm rate in Dosso and Zinder. In view of the obtained skills, one can stress the usefulness of this approach in this area of marked climate variability as a realistic step toward assessment of vulnerability to long-term climate change.

Significant predictors for the yield estimation of groundnut and cowpea include a wind erosion factor (WEF), which gives an indication on the importance of soil degradation in this region affected by desertification, the length of the rainy season (LRS) and the sea surface temperature anomaly of the third principal component of the global ocean (SSTA-EOF3). Secondly, the factors include rainfall in the three main rainfall months (R-JAS) and the amount of dry spells (DS; Table VII). This table shows further the differences between groundnut and cowpea among the three regions, but no clear pattern however, can be distinguished. Cautionary remarks for this type of analysis were presented in the preceding paper (Ben Mohamed et al., 2002).

For the year 2025, the two scenarios (a) with 10% reduction in rainfall and 10% increase in temperature and (b) with 20% reduction in rainfall and 20% increase in temperature, resulted in a reduction in the length of the rainy season (LRS) by 13 and 24%, or in a LRS of 97 and 85 days, respectively. This could have consequences for the types of varieties that can be cultivated. The potential impact on groundnut production, without new adapted varieties, for the three regions is for the first scenario minus 11% and for the second minus 25%. For cowpea, this is slightly different. The first scenario shows a drop in yield of 12% for Maradi and Zinder, but shows no effect for Dosso. For the second scenario, however, all three regions show a 30% lower yield for Maradi and Zinder and 25% for Dosso. Dosso is less affected by the climate change because of the higher rainfall in SP3 (Table II) and most likely by varieties that are adapted to the more frequently occurring dry spells in the three main rainfall months in SP3 (Table IV). Although the three regions belong to the same agro-ecological zone (soil type and precipitation), changes in temperature and precipitation seem to have different effects on the productivity of these crops, in contrast to millet (Ben Mohamed et al., 2002). Compared to millet, groundnut and cowpea are more sensitive to the assumed changes in climate because they have a less extensive root-system. In addition, they have a C_3-photosynthesis system which is more heat sensitive than the C_4-photosynthesis system of millet.

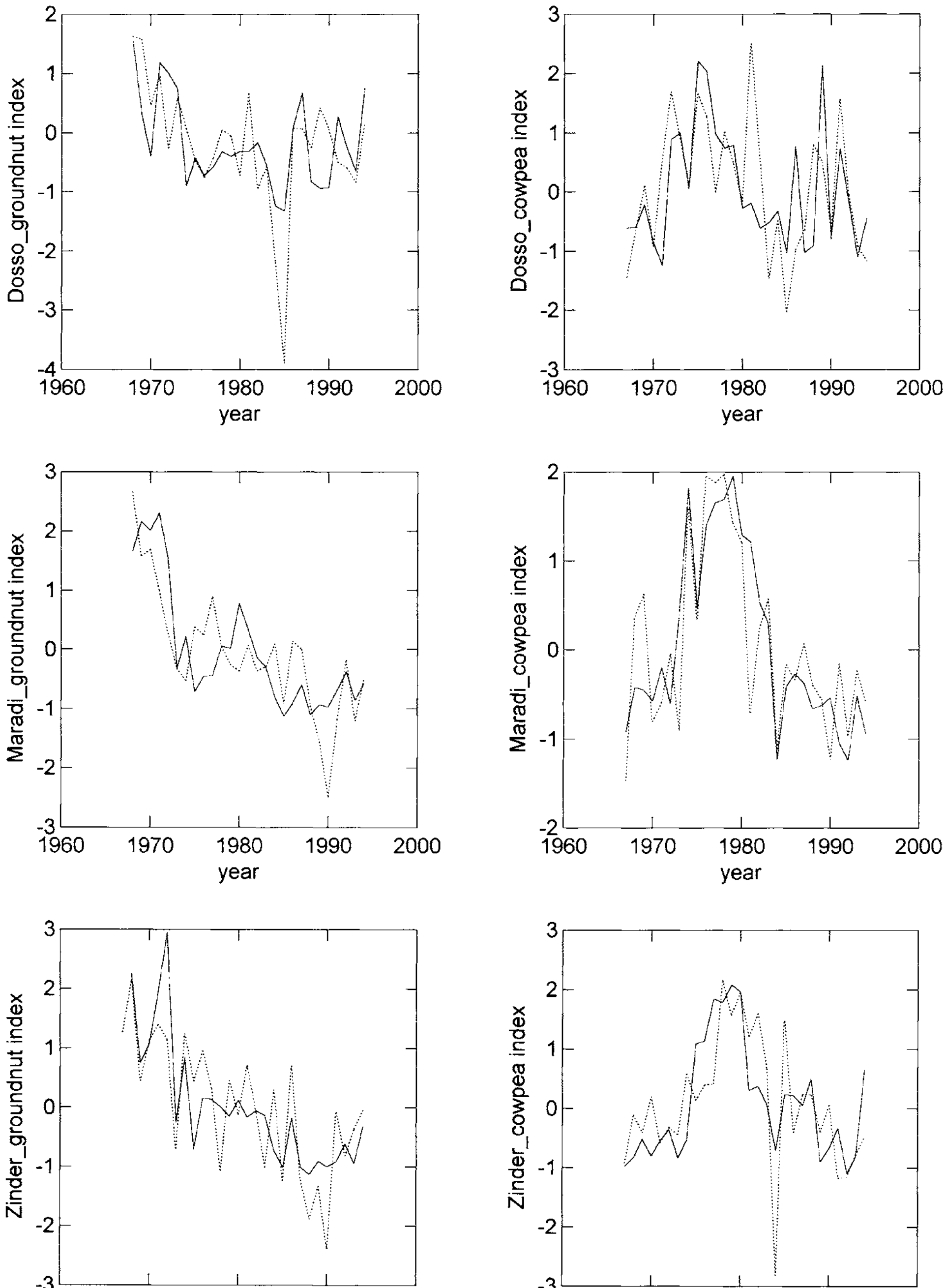

Figure 6. Indices for observed (solid line) and estimated (dotted line) groundnut production and cowpea yield for the three regions in Niger. Dosso, Maradi, and Zinder.

Table VI

Summary of ANOVA results and the model's performance for groundnut production (GP) and cowpea yield (CY) in the three regions in Niger

Modeled parameter		ANOVA			Model performance						
Location	Crop	R	F-ratio	P	Skill	HSS	C%	Category: < normal		Category: > normal	
								POD %	FAR %	POD %	FAR %
Dosso	GP	0.85	5.06	0	0.62	30	54	60	9	67	11
	CY	0.77	4.10	0	0.60	47	64	70	20	67	10
Maradi	GP	0.84	8.30	0	0.73	47	64	80	27	56	25
	CY	0.90	8.23	0	0.80	36	57	70	0	67	20
Zinder	GP	0.89	7.45	0	0.75	41	61	80	8	56	0
	CY	0.88	5.72	0	0.68	20	46	70	8	44	13

Table VII

Significant predictors of estimated groundnut production and cowpea yield in the three regions in Niger and their combined % of variance

Crop	Location	SSTA-Ind	SSTA-EOF3	RJAS	NRD	IRD	DS	T	WEF	LGS	RMG	RMC
Groundnut	Dosso		X						X	X	X	
	Maradi	X	X				X			X	X	
	Zinder			X	X	X	X		X			
Cowpea	Dosso		X						X	X		X
	Maradi		X	X	X	X		X	X			
	Zinder											

SSTA-Ind = Sea surface temperature anomaly of Indian Ocean; SSTA-EOF3 = Sea surface temperature anomaly of the third component of the global Ocean; R-JAS = Rain in July, August, and September; NRD = number of rainy days; DAR = Daily amount of rainfall; DS = dry spell; T = maximum air temperature in April; WEF = wind erosion factor; LGS = length of growing season; RMG = ratio of area of millet and groundnut; and RMC = ratio of area of millet and cowpea.

3.3.1. *Adaptation Strategies to Climate Change*

Some adaptation strategies to climate change have been reported for rainfed agriculture (Ben Mohamed et al., 2002). For groundnut and cowpea in particular, one can recommend the following to be investigated: (i) the impact of climate change in certain agro-ecological zones in Niger; (ii) the most appropriate sowing dates to optimize the available moisture in the soil and face the effect of eventual higher temperatures during the growth phase of the crop (e.g., through detailed crop simulation models); (iii) varieties that are the most tolerant to drought for zones with recurring drought periods; (iv) shortening of the growth cycle of high yielding varieties (Mounkaila and Idi, 1991); (v) development of varieties suited to different socio-economic niches (Freeman et al., 1999), (vi) use of irrigation or supplementary irrigation (cf. FAO, 1993; Amadou et al., 1999) and (vii) use of seasonal forecast by farmers in the planning of agricultural operations as well as greater agro-meteorological assistance and a strengthening of early warning systems (especially in view of rainfall distribution in the three main rainfall months).

4. Conclusions

The change that took place in the climatic conditions is certainly not the only cause of the drop in groundnut production. However, it served as a catalyst for a number of other causes that accelerated such a decline, notably, the preference of the farmer, in his quest for food self-sufficiency, for other crops such as millet and cowpea. This greatly contributed to reducing the land areas devoted to groundnut production. The seemingly temporary change in rainfall pattern also led to a reduction in the groundnut-farming zone through the southward movement of the isohyets. The repeatedly poor rainy seasons led to a shortage and reduction in quality of seeds. In the mid 1990s however, some revival in groundnut production was observed mainly because of improvement in various rainfall regime components: (i) increased total rainfall in July, August and September, (ii) increased number of rainy days, (iii) increased amount of rainfall per rainy day and (iv) reduced number of years with a dry spell of at least seven days per month. The climatic conditions in Zinder region, however, remain difficult for good groundnut production, mainly because of reduced length of the growing season. Future climate change, especially reduced rainfall and increased temperatures, will significantly further reduce groundnut production in these three regions of Niger.

For cowpea, the effects of inter-annual variability are less evident. Its cultivation seems more related to socio-economic conditions. As cowpea is better adapted to drier conditions, future climate change will increase the importance of cowpea, despite the estimated yield reduction.

To satisfy future human food demands, adaptive and strategic research for both crops remain necessary, especially to select the best suited varieties for the changing environment and identification of potential growing zones for these varieties.

Finally, it can be concluded that future climate change modeling should be linked to sufficiently small geographical units, such as regions, to translate theoretical results into practical recommendations. On the basis of our analysis of temporal and spatial variability of rainfall and temperature we are skeptical of the results of the present model for the entire Sahel or even for a country. We stress the need for further methodological research in this domain for the Sahel, which is highly susceptible to climate change.

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