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Chapter 7

SAHELIAN LIVELIHOODS IN THE REBOUND

A critical analysis of rainfall, drought index and yields in Sahelian agriculture

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Abstract
In this chapter an attempt is made to find statistical relations between rainfall, yield levels and the drought index. For the whole of the study region, average yield data was compared with average annual rainfall as derived from Meteorological services databases. Data from all available rainfall stations within such a study region was included to generate this simple average rainfall figure. Two drought indices were added to the analysis. No clear relation could be established.

1 MODELS AND DATABASES

To test assumptions about a statistical relationship between rainfall and crop yields in a region like the Sahel, and the usefulness of a 'drought risk assessment' approach (see Chapter 3 and 6) it is wise to consider the availability and reliability of rainfall and yield data, and which level of scale can be regarded as most appropriate for this analysis. Originally, the regional (district) level was considered the level for which data would be available. However, more lower-level data proved to be available than previously thought, though the quality of these data was limited because they were collected for an entirely different purpose (most often monitoring of national production by the Ministries of Agriculture of the respective countries).

For the whole of the study region, average yield data (as derived from secondary data sources such as regional, provincial or district Ministry of Agriculture statistical files and annexes) were compared with average annual rainfall as derived from Meteorological services databases. Data from all available rainfall stations within such a study region were included to form this simple average rainfall figure.

This method of average rainfall can be compared somewhat with that of the national Rainfall Index (RI) developed by Gommes and Petrassi (1994). The RI allows comparisons to be made between years and between countries. It is calculated for each country by taking a national annual precipitation average weighted according to the long-term precipitation averages of all the individual stations. Gommes and Petrassi demonstrate that the national RI is well correlated with national crop yield levels in Africa.

We also developed a Drought Index (DI). The Drought Index as we used it (see Chapter 6) needs data on precipitation, temperature and potential evaporation, and only weather stations measuring these data could be included in the analysis. However, since most weather stations do not gauge the last two variables on a year-to-year basis, it was decided to select those stations having time series on monthly precipitation (P) and having monthly averages on temperature (T) and potential evaporation (ETP). To allow for comparisons being made between data from different weather stations, only those stations were selected having precipitation data for the period 1960-1997. ETP can be determined in three ways, each having its own advantages and limitations (Dietz *et al* 1998). To get a reasonable spread of weather stations over our study area, it was decided to include all stations calculating ETP data, irrespective of the method used.

There are various advantages of the method used here for presentation of rainfall and drought trends in the form of the RI or DI. The country-size or regional scale is designed to correlate with other countrywide and regional statistics, especially on agricultural production. The RI as used by Gommes and Petrassi is independent of absolute amounts of rainfall, which may be very localized. It allows general comparisons to be made regarding an entire country. Because of the long-term record, a frequency distribution of RI values is available which allows historical comparisons to be made. And because a national index results, if the record is not complete for an individual station, the RI can still be calculated without that station. This permits a long-term record of the RI. There are several disadvantages as well. Because the RI is weighted by annual rainfall, those stations in wetter areas of a country (which, by nature, are often the more agriculturally productive areas) have a greater influence on the RI than stations in drier areas. The simple annual average as used by us does not have this problem, and the regional (provincial/ district) scale permits this if trends are correlated with agricultural data at the same scale. The DI can be regressed with higher-level data only, not permitting conclusions beyond the level of its analysis. Only part of the variability found at the lower levels is directly influenced by these higher-level variables. But both the RI by Gommes and Petrassi and the DI as used by us may be less useful when looking at overall drought conditions and the hydrological, environmental, and societal impacts resulting from it at any other level.

Similar problems are found with the agricultural production and productivity data. At the aggregate level, these latter variables, however measured, may be representative of regional trends, but at the level of the farm or plot, it may be that only a minor portion of production and yield variability as experienced by the decision making farmer is actually related to the rainfall situation of any particular season. All other variables, even those related to the actual DI used (soil moisture retention capacity, infiltration capacity, and thus the determinants of the soil moisture storage factor in the DI), are actually determined at the much lower level of scale: the farm, plot or even part-of-plot level. At the plot and farm level, labour, technology, inputs and other non-climatic and economic variables play an important role in determining the soil moisture storage factor, and this is methodologically difficult to include in the analysis as all these variables change over the years and most importantly within years by the reaction of decision makers on the rainfall of any particular year. We could therefore find that millet and sorghum crop yields in dry years are better than in wet years simply because more attention is being paid to these crops in dry years (reseeding on different plots, more labour in weeding and soil moisture infiltration, etc) to the detriment of attention for crops depending on relatively favourable rainfall patterns.

One way of finding out more about this problem of level of analysis and type of variable in relation to predictive value of the regression between rainfall regimes and production and yields is to do an analysis at more levels in the same region for the same period. This is what we retrospectively do (using all the data collected in the framework of the ICCD study) in this chapter. Data from the three case study areas for which we have detailed information at more than one level (Ghana, Mali and Burkina Faso) are being used to answer the above question.

2 AN ANALYSIS OF RAINFALL AND YIELD DATA FOR NORTHERN GHANA, MALI AND BURKINA

In the three countries concerned, four regions have been studied in depth, and the relationships between rainfall data, the drought index and various other variables have been studied. In Ghana, the

Bolgatanga region in the northeast, and the Upper West Region in the northwest have been studied. Here, the analysis of rainfall and yields remained at the regional level, without additional fieldwork to collect data at the village or household level as was done in the other countries of study. In Mali, data were collected at the village level in the region of Koutiala and Sikasso, but the aggregate data has been used here to do a similar analysis as is done for the northern Ghana region. And finally, in Burkina Faso data were used as collected by the Ministry of Agriculture and Animal Resources (MARA/DSAP) in the Kaya region of Sanmatenga and Bam provinces, and thus this analysis is also at the same regional level as the two in northern Ghana and Burkina Faso.

Northern Ghana

Usually, analyses at the higher levels of regions and states are characterised by high levels of correlation between rainfall and production and productivity figures over time (Brons *et al* 1999, Zaal & Oostendorp 2002). Various lower level sources of variability (individual, household and villages) even out, and major trends are isolated and show a high degree of correlation. The fact that these higher-level correlations are so low for the case of Ghana is therefore rather amazing and forces us to think of alternative models of yield predictions.

The data are presented below. They are based on the ICCD report on the northern Ghana region of Bolgatanga (Dietz & Millar 1999) and on an M.A. thesis on Upper West Region (Van der Geest, 2002).

Table 7.1 Yield estimates and correlations with rainfall and DI, Bolgatanga, Ghana, 1987-1997

Kg/ha year	Millet	sorghum	groundnuts	maize	rice	average	average rainfall	average DI
1987	562.4	639.1	1148	748	1052.1	873.98	983	0.7
1988	606.8	962.8	680.6	782	1235.8	873.98	936	0.9
1989	747.4	913	713.4	544	2004	942.72	1158	0.3
1990	518	763.6	606.8	748	668	716.86	808	1.7
1991	532.8	680.6	811.8	1300.5	1586.5	982	1050	1.7
1992	518	697.2	803.6	1003	1703.4	923.08	929	0.9
1993	1050.8	821.7	926.6	952	1636.6	1109.66	836	1.2
1994	747.4	713.8	852.8	850	2004	1001.64	1069	0.7
1995	1169.2	937.9	910.2	977.5	2404.8	1256.96	838	1.7
1996	1073	1203.5	787.2	901	2204.4	1227.5	976	2.6
1997	599.4	796.8	803.6	501.5	1803.6	864.16	864	2.5
Average	740	830	820	850	1670	982	949	1.4
Correlation								
Rainfall	-0.179	-0.032	0.016	-0.017	0.266	0.011		
DI	0.111	0.313	-0.155	0.187	0.159	0.120		
Corrected correlation (1989 deleted)								
rainfall	*-0.239*	*-0.177*	*0.228*	*0.376*	*0.170*	*0.074*		
DI	*0.207*	*0.506*	*-0.418*	*0.022*	*0.333*	*0.124*		

Note: The figures for 1989 were of doubtful quality, and have been deleted in the second correlation analysis. Pearson's correlation for rainfall, Spearman for DI were taken.

The correlation coefficients are not very high and apart from the correlation between rice yields and rainfall as a growth trend proxy none are significant. However, a number of conclusions can be drawn. First of all, the correlation between DI and crop yields is higher on average than between rainfall and crop yields, but the low coefficients for rainfall and the high but positive coefficients for the DI are surprising. The coefficients were expected to be high and positive for rainfall (more rain means higher yields, *ceterus paribus*) and high and negative for the DI (higher DI means more risk of crop failure). Also, the correlation between DI and sorghum is higher than for any other crop, but again it is *positive*, which is particularly unexpected as the DI was designed to predict yields for this relatively drought adaptive crop. For groundnuts, maize and rice, the DI appears not to be a good predictor at all. On the other hand, the correlation between rainfall figures and crop yields is extremely low and *negative* for millet and sorghum, and rather high and positive for groundnuts and for rice, which seems to imply that these crops are attracted by high rainfall conditions. This applies for rice even if yield is independent of the soil moisture content over the growing season with the use of irrigation. However, none of the coefficients is significant at the 0.01 level nor the 0.05 level.

Another rather interesting finding is that the outliers in the analysis seem to be the result of mistakes in the dataset, as the yields for rice and millet are similar in both 1989 and 1994. As the data for sorghum for 1989 are also too low for the rainfall of that year, it is assumed that the data for that year may be incorrect. Excluding these figures, the correlation coefficients are more extreme as is indicated in the lowest two lines of the above table. A clear negative relationship appears between groundnuts and maize (somewhat less pronounced) and the DI, and a high correlation appears between these crops and rainfall. This is what we would expect, so it seems the rainfall and DI data can be used to predict crop yields of maize and groundnuts, though for maize the relationship seems not to be very robust as the coefficient shifts between the two correlation analyses. Rice has a positive and high correlation with DI in the second analysis. The result for millet and sorghum and their relationship to rainfall and DI is even more problematic now than in the earlier analysis. Not only are the signs the same, they are now more negative (rainfall) and positive (DI) than before. Clearly, if not for the non-significant character of the relationships, there may have been truth in the remark of an old farmer in Bongo, North-eastern Ghana: ‘In a dry year there will be a good harvest. Formerly the young did not understand, but now they do.’ The question is: why would this be so?

To compare these data with another region in Ghana for which we have similar data, we now turn to the Upper West Region, where similar research was done in the framework of the ICCD project (Van der Geest 2002). The data are similar in structure, and are analysed in a similar manner. The following table presents the results.

Table 7.2 Yield estimates and correlations with rainfall and DI, Ghana, Upper West Region, 1986-1998

Year	Millet	Sorghum	Groundnuts	Maize	Yams	Average *	Rainfall	DI
1986	700	700	1300	900	6000	900	865.4	2.67
1987	700	700	1500	700	5100	900	822	1
1988	800	700	1700	1500	5100	1175	850.1	1
1989	600	600	1600	800	5000	900	1065.2	0.75
1990	800	1000	300	1000	7200	775	731.7	3.5
1991	600	700	800	1300	12000	850	1101.2	3
1992	700	900	800	200	13500	650	845.4	1.25
1993	1000	1400	1600	500	13600	1125	1078.1	0.75
1994	1100	1400	1600	1400	10500	1375	1167.1	1
1995	1100	1300	1500	1400	11000	1325	1420.4	1
1996	1100	1300	1200	1100	10800	1175	996.5	3.25
1997	1100	1100	1400	1000	10100	1150	1063.5	1
1998	1000	1200	1400	1100	8500	1175	958.4	2.25
Average	869	1000	1285	992	9108	1037	997.31	1.7
Correlation								
Rainfall	0.492	0.485	0.419	0.392	0.441	0.641		
DI	-0.055	-0.042	-0.854**	0.173	0.102	-0.382**		

Notes   ** Average of grain crops and groundnuts, excluding yams.*
** significant at the .01 level.
Rainfall and DI data on the basis of four stations, yield estimates from the Ministry of Food and Agriculture.
Pearson’s correlation taken for analysis of rainfall, Spearman for DI

Again, there is only one statistically significant relationship, that between the DI and groundnut yields. All the other relationships are insignificant at the 0.01 level (though significant at the 0.1 level for millet, sorghum and maize). At least, the relationships have the expected sign (positive for rainfall-grain yields, negative for DI and grain yields) with the exception of maize and yams. The correlation between average grain yields taken as an aggregate and rainfall is high and significant. Interestingly however, it appears that there is a steady growth of yields of the most important cereals over time, irrespective of rainfall or DI. Taken the year as indicating the trend, there is a high and significant correlation (r = 0.8 at the 0.01 level for both millet and sorghum). A similar relationship was found for rice in the Bolgatanga region (r = 0.7 at the 0.05 level). Gommes and Petrassi (1994) found similar evidence for Burkina Faso.

These results are less surprising than those obtained in the Bolgatanga region, and suggest that the data quality in the Bolgatanga may be at fault, or that other variables express themselves more in this region. These other variables do not induce a growth trend, as there is only a positive and significant correlation between rice and such a trend in the Bolgatanga region, while in the Upper West region all drought crops (millet, sorghum and yams) show a clearly positive and significant correlation.

The regional level analysis in Mali

The analysis in Mali departed on another footing, but for reasons of comparability we will first discuss data at the regional level, to continue afterwards with an analysis of the findings at village level. In the following table, data are presented on yield estimates, rainfall and DI, and correlations at the regional level for the Koutiala-Sikasso region in southern Mali.

This region of Koutiala-Sikasso is quite comparable to the northern Ghana region in terms of rainfall and DI levels and average grain yields. The correlation between rainfall and yields of the important cereals is from .67 to .87, which is reasonably high. One of the reasons may be that the data used for the analysis come from a large area, covering a 200 km North to South zone. This forces the rainfall as a variable to the front, while at the lower levels and in smaller areas rainfall is similar for most sites, and other variables appear to be important.

Table 7.3 Yield estimates and correlations with rainfall and DI, Mali: Koutiala and Sikasso, 1984-1998

Kg/ha Year	Millet	Sorghum	Maize	Groundnut	Cotton	Rice	Average rainfall	Average DI
1984	1047	1233	1328	715	1251	745	914	2.3
1985	1324	1093	1537	939	1240	905	1017	2.0
1986	1186	1017	1802	1120	1329	1183	1103	1.7
1987	879	953	1385	992	1307	1241	977	1.0
1988	1028	750	1309	832	1340	905	893	1.0
1989	889	852	1385	875	1184	1679	993	2.3
1990	1146	1030	1575	768	1352	964	989	3.5
1991	1087	979	1707	1024	1262	1562	1101	1.0
1992	622	712	1347	768	1095	1343	854	1.0
1993	543	623	1157	587	1240	1591	833	2.0
1994	771	674	1347	800	1095	1343	874	
1995	781	801	1556	854	1251	1372	958	
1996	988	1271	1897	1067	1117	1460	1128	1.0
1997	860		1674	653	1066	1256	934	1.9
1998	948		1812	759	1020	1340		
Average	940	922	1521	850	1210	1259	969	1.7
Correlation								
Rainfall	0.673**	0.703**	0.870**	0.852**	0.211	0.115		
DI	0.226	0.220	-0.177	-0.467	0.087	-0.162		

Note: *Rainfall estimates on the basis of nine stations, DI on the basis of the three stations for which the necessary detailed data is available.*
*** Significant at the 0.01 level*
Pearson's correlation used for rainfall, Spearman for DI.

However, both cotton (coefficient of .21) and rice (with .11) have very low coefficients, indicating that for the region as a whole, there is no clear relationship between rainfall and yields for these two crops. We will see later that within this zone, rice and cotton production does tend to be attracted by adequate rainfall conditions. All correlations between grain crops (and groundnuts) and rainfall are highly significant (at the 0.01 level).

The same does not apply for the relationship between DI and crop yields. Unexpectedly also, the correlations between DI and yields for the various products appear to be variable. For groundnuts, it is high and negative, as expected, but for the other products the coefficient is either low and negative (maize) or even positive (millet and sorghum). Rice shows a negative and relatively high coefficient, but cotton shows a positive and reasonably high coefficient, which is remarkable. None of the coefficients is significant at the 0.01 or 0.05 level. These findings again point at the inadequacy of the DI to predict the yields of dryland crops such as millet and sorghum at the level of the region. It implies some serious thinking will have to be applied on the adaptation of the index if it is to be used in dryland research other than in the area where it was originally developed (in India).

Comparing the analysis in Ghana and Mali, the conclusion may be that the data for Ghana (and especially the Bolgatanga region) are probably incorrect as the correlation coefficients are generally lower than in the case of Mali, while the level of analysis and the general size of this region (North-South) are comparable. The fact that in both cases there does not seem to be a proper relationship between positive rainfall and negative DI correlations indicates that the DI may be inappropriate. The Upper West Region data take a position in between these two extremes.

The village-level analysis in Mali

The village-level analysis in Mali departed from an extensive database, including variables related to land use, crop productivity, farm characteristics, village characteristics, and economic and bio-physical external conditions (Brons *et al* 1999). The data was restructured to allow an analysis at village level. Principle Component Analysis was applied to reduce the dataset into an number of independent components that reflected systematically village characteristics. Subsequently, for a limited number of important cropping systems, multiple regression analysis was applied. We will follow this route to arrive at an analysis of one of the most important cropping systems in the discussion on rainfall-yield relationships.

The result of the PCA is a reduction for 43 villages of 26 variables into 7 main components or factors (Brons *et al* 1999: 19-20). Cumulative percentage of explained variance is 76 percent. The components can be described as follows:

Commercial grain production

This factor is characterised by a substantial village area of diversified grain production for commercial purposes (rice but also maize, millet and sorghum) that are able to realise high gross margins and revenues. Moreover, the joint high yield levels of groundnut points to some diversification that is taking place into the production of leguminous crops, and positive effects of generally high input levels. It should be noted that this strategy could only be followed when rainfall risks (e.g. low rainfall but also high variability) are limited or controllable.

Commercial cotton production

This factor indicates high investments for input purchases in commercial cotton production realising a surplus that can be used to satisfy consumption expenditures. Specialisation in cotton production is mainly feasible due to favourable agro-climatic conditions (high rainfall and low rainfall variability) that enable substantial investments for input use.

Livestock farmers

Villages where farmers possess relatively high amounts of cattle and oxen can be found in the Northern region (where livestock production has a comparative advantage) and in the cotton areas, which are characterised by relatively favourable land endowments. Investments for cattle purchases here are usually financed out of (earlier) cotton revenues, a crop that has now all but disappeared from this region. Inputs for livestock production are limited and returns per hectare are low. Part of the livestock production is located close to villages and specialises on dairy products. The population in these villages relies on commercial purchase of grains to satisfy food security and is very successful in this respect. These villages are not significantly affected by soil degradation. This can be understood from the recent understanding that pastoral and livestock production as a system may be better adapted to local ecological restrictions and a high market involvement than was previously understood.

Commercial rice production

Villages that diversify into rice cultivation and specialise into it as far as grain production is concerned are strongly dependent on stable rainfall patterns. Rice was introduced originally as a major diversification crop and initial investments are financed out of cotton revenues, which are relatively high per area unit. In the medium term, the farming systems become more dependent on rice as a major crop, thus leading to a new type of specialisation at village level. Farmers with limited land resources mainly select commercial rice production: those who are able to exploit a labour-intensive cropping system albeit with low labour productivity. It again points at the favourable relationship between market involvement and food security considerations, which depends on a specific set of variables to make it possible, such as distance to markets.

Extensive grain production

Villages that have the availability of a large area per person can still rely on extensive grain production for food self-sufficiency. The availability of oxen facilitates the required land preparation and weeding activities for an extension of the cultivated area. Reliance on extensive grains production mainly occurs in villages with low, but stable rainfall patterns. This system guarantees high net revenues (low external input costs) and adequate food security levels. Apparently, the high-income levels encourage activities in the non-agricultural sector (as a relationship vice versa could not be established). This is the component with the highest score on the number of non-agricultural activities per 1000 habitants.

Sustainable subsistence farming

This component does not appear with any significant factor score in any of the agricultural indicators or rather, it appears as the only component which scores high only on indicators of what it may not be: it is not degraded and not close to services, the latter pointing to less favourable socio-economic conditions. With little agricultural development, low land use intensity and a favourable state of the natural resource conditions compared to the other components, it is a componentthat seems characteristic of an early stage of agricultural development in the region, now only found in remote areas.

Marginal subsistence farming

In the less developed villages with relatively few farms equipped with oxen traction and little non-agricultural activity, farmers maintain diversified farming systems without particular implications on yield levels. These farmers avail of a small number of livestock and often of incomplete equipment only. Due to the large distance to the cities off-farm employment options are equally limited. Low levels of education and health also inhibit participation in the labour market. The combined effect of the features in this component is a regular occurrence of food shortage. This component compares unfavourably with the former in that the food security situation is rather bad.

We will present an analysis, estimating the importance of the various inputs and conditions including rainfall in agriculture at the level of the villages. A limited number of cropping systems are particularly relevant here. An analysis of all crops and the determining variables of productivity will be relevant for all components, and in particular the dominant systems of commercial grain production, commercial cotton production, livestock farming, commercial rice production and extensive grain production. The grain producing cropping systems, whether commercial or otherwise, will be analysed separately, as well as the cropping system for maize, which is the only grain for which correlations of the expected level and sign were found in the regional analyses of Ghana and Mali (and Burkina Faso as we will see) were found. We present a limited number of production functions: gross revenue per ha is estimated for all crops taken together (all the above components), for grain production and for maize. Table 7.4 shows the result.

This analysis shows that, in the complete model, for all cropping systems identified earlier as components, rainfall does not appear as a significant variable which can explain revenues. Rather, inputs in terms of human labour and animal traction are the determinant. For the grain-production based components, rainfall does appear, but the labour inputs are again important, as are the soil characteristics. This illustrates the labour intensive character of grain production in this area, while the appearance of the degradation variable and soil characteristics in general may be interpreted as being the expression of a process of soil mining taking place during intensive grain production in the absence of adequate input levels.

Table 7.4 Gross revenue per ha, Cobb-Douglas production functions, complete and reduced model

Complete model	All crops			Grain			Maize		
	Coef.	t-value	Sign.	Coef.	t-value	Sign.	Coef.	t-value	Sign.
Intercept	-2.75	1.231		3.85	1.348		1.06	0.347	**
Total Area	0.08	0.826		0.00	0.039		0.12	0.896	**
Rainfall 1997	0.66	2.184		0.35	1.701	**	0.29	0.697	
Persons per ha #	0.27	1.663	*	0.48	2.369	**	0.51	2.340	
Oxen per ha #	0.41	2.541	**	0.67	1.744	**	0.46	2.067	*
Expenses per ha	0.02	0.142		-0.05	0.323		-0.00	0.003	**
Degradation index	0.07	1.480		0.12	2.158	**	0.09	1.505	
Clay dummy	0.18	1.515		0.36	2.325	**	0.47	2.871	
Sand dummy	0.19	1.690		0.24	1.617		0.31	2.017	
Distance education	0.02	1.415		0.01	0.862		0.02	1.198	
Drought index 1997	0.01	0.071		0.05	0.532		0.07	0.732	
Adjusted r-square	*0.47*			*0.31*			*0.29*		
Reduced model									
Intercept				5.42	2.413	**			
Rainfall 1997	0.72	3.257	***	0.54	1.851	**			
Persons per ha				0.44	2.278	**	0.50	2.441	**
Oxen per ha	0.37	2.363	**				0.41	1.869	**
Expenses per ha	0.06	1.737	**				0.10	2.132	**
Clay dummy				0.1	1.844	**	0.40	2.505	**
Sand dummy				0.21	1.686	*	0.25	1.693	**
Adjusted r-square	*0.47*			*0.29*			*0.34*		

Notes: *Rainfall based on May-October figures (94 percent of total). Clay and Sand dummies as opposed to gravely soil. Significance levels are one-tailed.*

For the maize cropping system in particular, total area cultivated, and again the inputs in terms of animal traction and expenditure on fertilisers appear as significant variables. The reduced model shows that rainfall is a significant variable at the level of all cropping systems, and for grain-based production in general, not so much for the maize production based cropping system. Maize, and cereal based cropping systems revenues generally are influenced by input levels (labour, expenses) and soil characteristics. The relatively lower r-squares show that at the level of the villages studied, the explanatory power of the models is lower than the simple models at the regional levels of Ghana, Mali and Burkina Faso, and even lower than the r-square value of a similar production functions for the study region in Burkina Faso, as we will show. For all cropping systems together, rainfall does appear as the most important variable in explaining variability in revenues. In all cases, except for maize, rainfall is an important determinant of crop yields and revenues, but sufficient rainfall is most important for farmers specialising into commercially oriented (grain) strategies. Access to external inputs has most influence on aggregated gross revenues and on maize yields, whereas animal traction is especially important for maize production. Access to land is hardly ever a constraining factor, but access to sufficient labour is most relevant for both commercial and subsistence cereal production.

The household level analysis in Burkina Faso

The analysis in Burkina Faso departed on a comparative basis of data sets from two different periods, and analysed the relationship between climate and other variables with production, productivity and land use change at the household level. Again, for reasons of comparability we will first discuss data at the regional level, to continue afterwards with an analysis of the findings at household level.

In the following table, data are presented on yield estimates, rainfall and DI, and correlations at this regional level.

Table 7.5 Yield estimates and correlations with rainfall and DI, Burkina Faso, 1984-1998

Kg/ha Year	Millet	Sorghum	Maize	Groundnut	Cotton	Rice	Average rainfall	Average DI
1984	407	376	109	396	377	2036	490	2.7
1985	533	514	715	505	191	2068	459	3.3
1986	529	618	617	618	568	1437	518	2.7
1987	300	328	153	357	388	1882	451	1.7
1988	776	704	1445	818	534	921	724	2.0
1989	376	474	617	985	777	1613	603	3.3
1990	428	498	1048	706		197	503	3.0
1991	639	841	595	453		255	712	3.3
1992	495	765	1055	1398		255	650	2.0
1993	608	851	1003	880	957	1918	564	2.3
1994		689	794	801	187		943	1.0
1995	546	709	890	703	431		648	3.3
1996	495	629	1048	1000	500		613	2.0
1997	288	381	210	308	236	431	554	2.0
Average	494	598	736	709	468	1183	602	2.5
Correlation								
Rainfall	0.685	0.677	0.391	0.315	-0.052	-0.529		
DI	0.156	0.025	-0.034	-0.154	0.259	0.058		
Correlation on the basis of the period 1968-1997								
Rainfall	*0.614***	*0.558***	*0.330*	*0.103*	*-0.128*	*0.140*		
DI	*-0.130*	*-0.174*	*-0.047*	*0.084*	*0.037*	*-0.091*		

Notes: Rainfall figures are derived from the nine stations within the study region. DI figures are based on figures for Kaya, Ouahigouya and Tougouri stations. Yields are based on data for Sanmatenga Province in which much of the Kaya region is located. Empty cells have no data.
*** significant at the 0.01 level*

As in the earlier cases, there is variation across the various crops as to the correlation between rainfall and yields, with millet and sorghum having high, positive and significant coefficients between rainfall and crop yields, and low and positive (though insignificant) coefficients between DI and yields. This is similar to what was found in Mali and at this level, the level for which it was designed, it seems the DI is not doing what it was expected to do. Correlations between rice yields and rainfall and DI rice are quite similar from what was found in Mali. The fact that yield levels fluctuate enormously gives reason to be careful.

But for other crops, it can also be said that higher rainfall levels do not always predict higher yields. We plotted the data for groundnuts, and it appears that the correlation between rainfall and yields for this crop becomes ever more negative in the course of the last few decades. The following plot shows the result.

Figure 7.1 Relationship between rainfall in mm and groundnut yields in kg per ha, per decade, 1970-1999

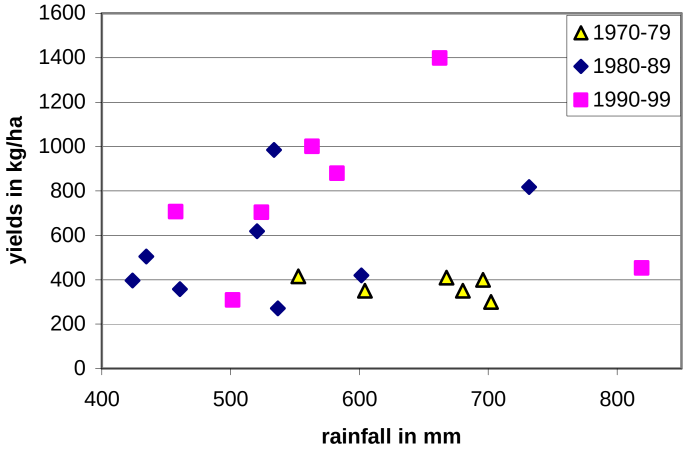

Table 7.6 Changing relationships over time between rainfall and groundnut yields

Period	Slope of the linear regression coefficient
1970-79	-0.32046
1980-89	1.0947635
1990-99	0.1458791

The relationship changes in the course of time, indicating there is an intervening variable being hidden in the data set as presented in table 7.5. It may be caused by the selection of new varieties of groundnuts responsive to favourable rainfall and high input levels. The lowest yields, occurring at low rainfall levels, are not below the level of the earlier varieties, while the highest yields occur with average rainfall levels and are very much above the highest yields achieved before. It may also well be that we see the effect of adaptation to these average rainfall levels, with low yields when there are very low and moisture is short, and high rainfall levels when damage through disease and water logging or flooding may occur. The graph also shows the resilience of the earlier system where yields of around 400 kg per hectare where achieved regardless of the rainfall level.

The household level analysis in Burkina Faso

For the household level analysis of yields and its independent variables, a dataset was used for the period 1993 to 1998, as collected by the monitoring and data collection service of the Ministry of Agriculture and Livestock Resources (MARA/DSAP), the *Enquête Nationale sur l'Agriculture* (ENSA) (Brons *et al*, 2000). This dataset was collected at the household and plot level, and is much more detailed though with a certain bias towards the purpose of its collection.

The following production function shows the result for the analysis of yields in kg/ha of millet and sorghum (as first crop). Information on the database and the regions are presented in Brons *et al*. (2000).

Table 7.7 Yields of millet and sorghum in kg per ha, Cobb-Douglas production functions, per region

Note: *The dummies are defined as opposed to no application of the relevant variable, except for Household plot (versus individually owned plot), Plain (versus basin-located plot), Slope (idem), Near village (versus at a distance) and Sorghum (versus Millet).*

Complete model	South			Centre			North		
	Coeff.	t-value	Sign.	Coeff.	t-value	Sign.	Coeff.	t-value	Sign.
Area	1.072	13.7	***	1.168	14.7	***	1.230	18.4	***
Labour	-0.001	0.1		-0.120	1.5		-0.159	2.4	***
Fertiliser	0.026	2.7	***	0.014	2.1	**	0.015	2.0	**
Rainfall	-0.096	0.3		0.059	0.3		0.392	2.9	***
Dummies									
Intercept	-3.188	1.7	*	-4.074	2.9	***	-6.541	7.5	***
Manure	0.104	2.2	**	0.108	2.6	***	0.013	0.3	
Manual soil preparation	-0.062	0.6		0.044	0.4		0.232	2.2	**
Animal soil preparation	0.068	0.9		0.001	0.0		-0.063	1.1	
Erosion control	-0.012	0.2		0.065	1.6		0.007	0.1	
Household plot	0.485	4.7	***	0.294	2.5	*	-0.112	0.7	
Cowpea intercrop	-0.019	0.3		-0.015	0.3		0.370	0.6	
Other intercrop	-0.101	0.9		-0.106	1.6		-0.041	0.5	
Plain	-0.097	1.5		-0.067	1.3		-0.050	0.9	
Slope	-0.148	1.8	*	-0.282	3.7	***	-0.123	1.0	
Near village	0.129	3.0	***	0.067	1.5		0.720	1.6	
Sorghum	0.160	3.9	***	0.149	3.9	***	0.091	2.1	**
Adjusted r-square	*0.79*			*0.78*			*0.79*		

Household characteristics other than labour were not significant and were left out of the model. Other variables at plot level are available but the data quality is limited and dummies were included to capture at least some of the explanatory power of these variables at this level.

Marginal productivity of land is the single most important and most significant variable in the model, with fertiliser application as a second. Labour appears only as a significant variable in the north, but with a negative sign. Probably, other and unobserved household characteristics are influential in explaining output variability from the labour coefficient. Rainfall appears only as a significant variable in the most northerly zone of the study while in the other zones it is not significantly different from zero.

The dummies show that the southern and central zones have quite similar significant scores on the dummy variables, with manure application and variables indicating access (both in terms of ownership and spatially) are important as well. Slope as opposed to basin location of fields is significant in these two zones as well, with the expected sign. Soil preparation in the north is a significant variable.

Concluding one could say that at the household level, the area and fertiliser use are the most important factors in explaining yield differences, with rainfall being important and significant in the north only. Of the dummies at plot level, variables pertaining to access to land and manure (south and central) and manual soil preparation are significant and of the expected sign, though the coefficients are not always very high.

3 CONCLUSIONS FROM THE CASE STUDIES

It remained unclear for long why there should be no negative relationship between millet and sorghum and the DI in some cases. Together with the evidence from Mali and Ghana, we can now say that the DI, though developed for dryland regions and dryland crops, does not seem to predict yield levels very well. Also, it is now questionable whether the data on the Ghana Bolgatanga area are correct, when set against a similar analysis (at the similar level of the region) in another region of Ghana and in two other countries. The DI coefficients for the other crops in Ghana are also not very high, and often have the wrong sign. The data and findings at regional level for Mali are more comparable with those of Burkina Faso, with the exception of rice and cotton perhaps. For the Sahelian-Soudanian region as a whole there is no clear relationship between rainfall and yields for the two cash crops of rice and cotton. Within this zone, rice and cotton production does tend to be attracted by adequate rainfall conditions, which indicated that though the production and yields of these cash crops is insensitive of actual *annual* rainfall, it still needs higher *average* rainfall, harnessed through soil and water management. In areas where it is cultivated in lower lying areas (the *bas fonds*), the highest rainfall levels cause damage causing the crop to be more affected by flooding than by drought. Despite all, the average rainfall remains a better and more significant predictor of yields, particularly of the dryland crops of millet and sorghum, than the DI.

Still, for some low correlations, some remarkable explanations may be found. The example of groundnut yields in Burkina Faso shows that the data, when split in decades, show that considerable yield increases can be expected for rainfall levels around the average, either as a result of a process of adaptation of crops to the rainfall regimes, or as a result of soil selection for this crop and the addition of other inputs such as fertiliser, manure or labour.

The two Cobb-Douglas production functions, though different in implementation, show comparable results when we look at grains in the case of Mali and Burkina Faso.