

Article

Climate and Food Production: Understanding Vulnerability from Past Trends in Africa's Sudan-Sahel

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Abstract: Just how influential is rainfall on agricultural production in the Sudan-Sahel of Africa? And, is there evidence that support for small-scale farming can reduce the vulnerability of crop yields to rainfall in these sensitive agro-ecological zones? These questions are explored based on a case study from Cameroon's Sudan-Sahel region. Climate data for 20 years and crop production data for six major food crops for the same years are used to find patterns of correlation over this time period. Results show a distinction of three periods of climatic influence of agriculture: one period before 1989, another between 1990 and 1999 and the last from 2000 to 2004. The analysis reveals that, while important in setting the enabling biophysical environment for food crop cultivation, the influence of rainfall in agriculture can be diluted by proactive policies that support food production. Proactive policies also reduce the impact of agriculturally relevant climatic shocks, such as droughts on food crop yields over the time-series. These findings emphasize the extent of vulnerability of food crop production to rainfall variations among small-holder farmers in these agro-ecological zones and reinforce the call for the proactive engagement of relevant institutions and support services in assisting the efforts of small-scale food producers in Africa's Sudan-Sahel. The implications of climate variability on agriculture are discussed within the context of food security with particular reference to Africa's Sudan-Sahel.

Keywords: rainfall; Sudan-Sahel; small-scale farmers; climate vulnerability; yields; droughts; PDSI; food security; climate variability

1. Introduction

The problem of food insecurity and the threat of starvation, childhood malnutrition and under-nutrition in the Sudan-Sahel of Africa is recently making headlines in major global news outlets. The World Food Programme of the United Nations reports that approximately 10 million people are critically short of food in the Africa's Sahel [1]. Here, countries, such as Niger, Burkina Faso, Chad, Mali, Mauritania, Cameroon and Nigeria, have declared states of emergency in affected regions. In the most severe cases, in countries, such as Mali, Niger and Burkina Faso, millions of people (especially women, children and adolescent girls) are in acute need of emergency food assistance. It is feared that the 2012 crop failure that may result from a looming drought in the region may bring another 12 million people in need of food assistance [1–3]. The present food crisis follows that of last year (2011) in which 13 million people living in a similar agro-ecological zone in the Horn of Africa needed food assistance [1].

While food assistance has the potential of alleviating the food crisis in the short-run, one of the main problems of food security in this region is that of low levels of production [2]. Increasing levels of food production can improve the food availability component of food security. Other problems have to do with different components of food security (access, utilization and stability). Low levels of inputs (nutrients, seeds, irrigation), limited mechanization and less optimal cultivation techniques are advanced as reasons for low levels in Sub-Saharan Africa [2,4]. Low production levels of staple food crops may, in some cases, sustain households, albeit marginally. Such marginal sustenance with staple foods is seen only as a first step towards truly reducing hunger [2]. A more comprehensive food security pathway must involve a transformation of agriculture beyond staple food provision. Agriculture should evolve to provide sufficient protein, vitamins and trace elements necessary for healthy households [2]. In the last decade, there is increasing evidence that the sustenance of basic staple food needs for millions of households in Sub-Saharan Africa is persistently being threatened [2,5]. Droughts and variable rainfall patterns that have affected parts of the West Africa Sahel and the Horn of Africa have been blamed for much of the food security problems that have affected these regions in the last decade [2].

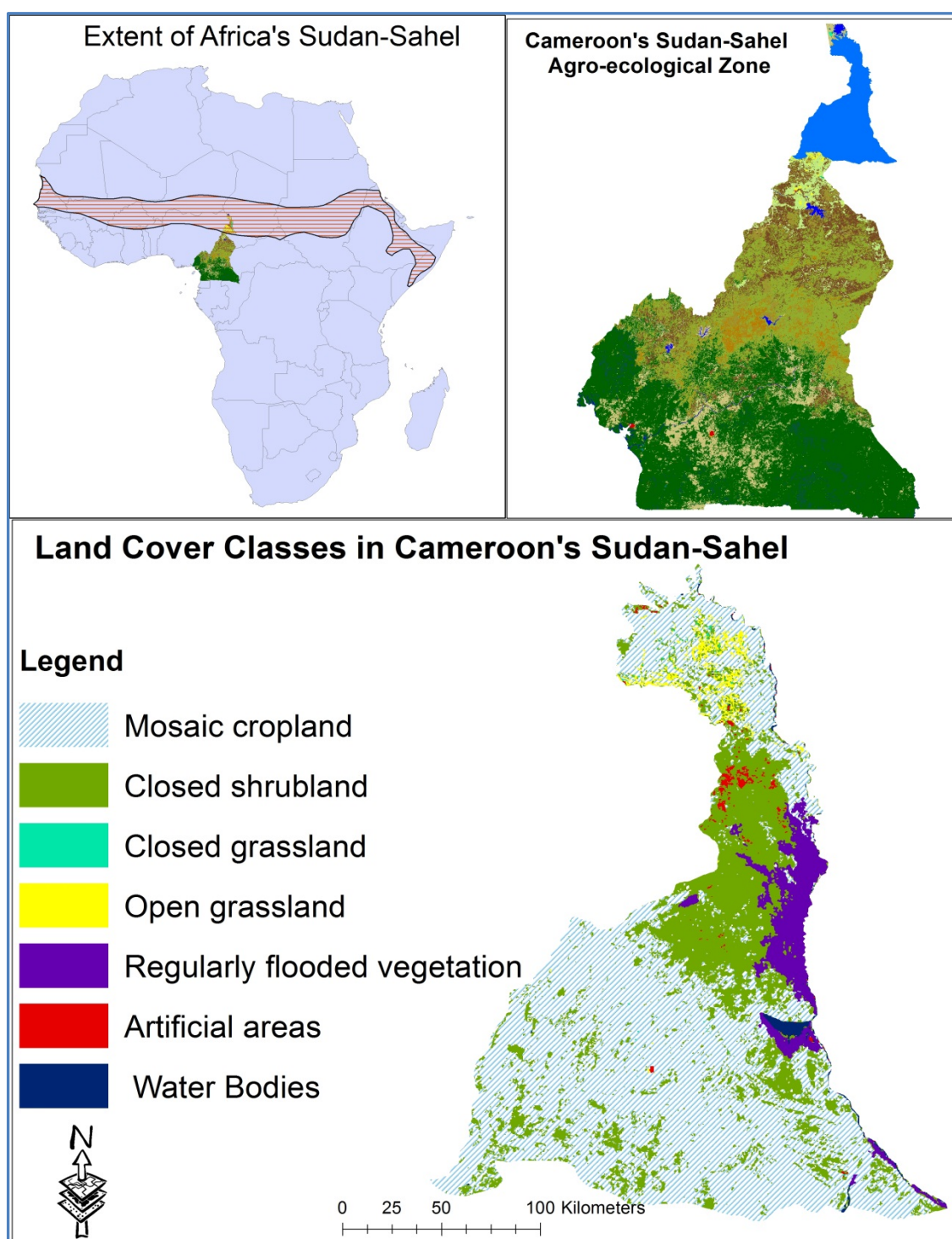
It is estimated that less than 5% of agriculture is irrigated in countries of Africa's Sudan-Sahel [6], notwithstanding the major role played by agriculture in the socio-economic lives of its people. Most of the agriculture depends heavily on rain-fed production for a majority of the food produced and consumed within this region. Evidence has established a link between rainfall variability and fluctuations in the growth of Gross Domestic Product (GDP) for countries that are heavily dependent on rain-fed agriculture for food production [7–9]. For countries in Africa's Sudan-Sahel, agriculture contributes an important share to the GDP, and so, variability being one of the main factors on which most of the agricultural production in the region depends is likely to have an effect on the GDP. An understanding of the relationship between climate variability and change (especially of rainfall) is therefore important in informing decision-making on the needs and strategy for adaptation and resilience building. It is an imperative for achieving different dimensions of sustainable development for this region. Identified threats to such sustainable futures, which directly relate to rainfall variability, are food security [10,11], water conflicts, threats to livelihoods [10], economic growth [7,8] and regional political strife [11,12].

This study set out to examine the relationship between climate and food crop production in the Sudan-Sahel agro-ecological zone of Africa at a very local scale. Drawing from meteorological and crop production data from the field, major trends and relationships between key climatic factors for food production in this region are examined. As a case study of the relationship between climate and agriculture, the choice of Cameroon's Sudan-Sahel agro-ecological zone is interesting for a number of reasons. It borders the Sahara desert and, so, has dry seasons, which are severe for the production of food crops, limiting this area to a single annual cropping cycle for most crops. This makes the region particularly sensitive to identified effects of climate change on agriculture, such as rainfall variability, floods and droughts. Its short vegetative season further limits the number of crops that can be grown in the region. In the past, this region of Cameroon had depended heavily on fishing from Lake Chad for an affordable source of household dietary protein and household income, a resource that has been seriously jeopardized by the steady shrinking of this lake. It is one of Cameroon's most densely populated regions with one of the highest rates of population growth. Added to the burden of providing sufficient food to feed its own population, this region is a major reception hub for refugees from neighboring countries with recent political strife (Chad, Central African Republic, Sudan and Northern Nigeria). Most of these characteristics are common in the Sub-Saharan countries where this agro-ecological zone extends. With regards to food production, it can therefore be argued that this region is at the frontline of present and future climatic constraints to self-sufficiency and future food security.

2. Description of the Study Area

The Extreme North region of Cameroon has a surface area of 34,263 Km², with six administrative divisions (Figure 1). In 2010, the population was about 3.48 million, with about 24% living in urban areas. The climate type is Sudano-Sahelian, which is characterized by generally low mean annual rainfalls and recurrent droughts. The average annual rainfall is between 700–850 mm. While the rainy season lasts from late April to early October, the bulk of rainfall occurs from May to September. The mean annual temperature is 27.9 °C, with an annual temperature range of 12.5 °C. The climate data used in this study was collected at one of the main meteorological stations of the region located at Maroua-Salak, on latitude 10°27', longitude 14°15' and 421m above sea level (Figure 1).

Agriculture is the main economic activity in the region. Three main soil types dominate the region and provide favorable conditions for the cultivation of its major food crops. The sandy soils on the plains favor the cultivation of millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*) and groundnut (*Arachis hypogaea*). The rich alluvial loam soils along streams and river banks are used to grow maize (*Zea mays*) and sweet potato (*Ipomoea batatas*). Soybeans (*Glycine max*) and cowpeas (*Vigna unguiculata*) are grown on clay soils [13,14]. The main cash crops of the region are rice (*Oryza sativa*), cotton (*Gossypium barbadense*), onions (*Allium cepa*) and gum-arabic (*Acacia Spp.*) [14]. Livestock plays an important role in the economic landscape of the Extreme North region. The main breeding areas are plains of the River Logone, the Diamaré plain and regions of the Mandara Highlands [13]. In the heavy population centers of the region, severe water shortages limit the practice of any viable form of agriculture to only about three months in a year. These are areas around Yagoua, Kaélé, Tokombéré and Mora, where a majority of livelihoods are built around small-scale livestock production, handicrafts and tourism [13].

Figure 1. Location of the study area.

3. Methods

3.1. Sources of Data and Analysis

Regional climate data for the region was derived from the National Meteorological Office in Douala, Cameroon. It consisted of monthly rainfall and temperature for the region from 1960 to 2008 and daily rainfall data from 1969 to 1999. While the monthly data from 1960 to 2004 was consistent, entries beyond 2005 had lots of missing data and were not used in the analysis. The monthly data was

used to examine agro-climatological variables relevant for food crop production in the region. These include annual and seasonal rainfall totals and anomalies, annual and seasonal temperature values, as well as trends of the time-series. In the same light, the daily data beyond 1994 was not used in the analysis, because of the existence of missing values. Daily rainfall data was used to compute annual trends in the number of rain days, high daily rainfall events, start of the rainy season and the length of dry spells. High rainfall was defined as inputs ≥ 40 mm of precipitation per day. Using information from field studies in the study region, the agricultural calendar and advice from farmers and agricultural development experts in the region, a definition of the start of the rainy season was made. For this study, the start of the rainy season is defined as any day after the 21st of April where precipitation totaled over five days is ≥ 20 mm, with at least two days of rainfall within this five-day period. This condition would only define the start of the rainy season if there should be no dry spell that exceeds five days within the next 30-day period. According to agricultural experts in the region, these three conditions combine to characterize a reliable onset of rains in which the probability of dry spells that would destroy germinating seeds or young plants is significantly reduced. These agro-climatic features were analyzed with INSTAT[®] software, developed by the Department of Statistics, University of Reading, United Kingdom.

Data on the total area cultivated, yields and total production of six major food crops were derived from the Far North Regional Delegation of Agriculture and Rural Development. These crops are maize, wet and dry season sorghum, millet, groundnuts and cow peas. The Regional Delegation of Agriculture is the regional representative of Cameroon's Ministry of Agriculture and Rural Development, in charge of overseeing and implementing the government's policy of agricultural development in the administrative region. Part of their work involves collecting, analyzing and disseminating data on agricultural production, constraints and development. This data received from the delegation covered the period 1984–2008. However, only data for the period 1984–2004 is studied, because beyond 2004, the data was not consistent for all crops. This is because the government's new approach to supporting agricultural development does not provide equal resources or attention to all crops. For example, crops such as maize and sorghum receive more attention and development resources than others, such as millet and cowpeas. This is owed to the growing economic value of maize and sorghum in the local and regional markets.

Given the established importance of rainfall as a constraint for food crop cultivation in Africa's Sudan-Sahel, linear regression analysis is used to investigate the relationship between yields and a number of climatologies used in the study. Since all of the rainfall occurs during one defined season, which is the cultivation season for most of the crops of this zone, it is reasonable to assume that the total annual rainfall is the rainfall that is used for crop cultivation. Correlations of total rainfall and crop yields for different periods of the time-series are computed using the Spearman's Rank correlation routine. Linear regression is used to compute the amount of yield variation that is explained by rainfall variation, as well as the variation in yield explained by droughts in the study area. To compare parameters of different units and scales, such as total rainfall (in millimeters) and yields (in tons per hectare), the data was standardized based on the formula:

$$z = (x - \mu) / \sigma \quad (1)$$

where z is the z-score, x is the data point, μ is the mean and σ is the standard deviation.

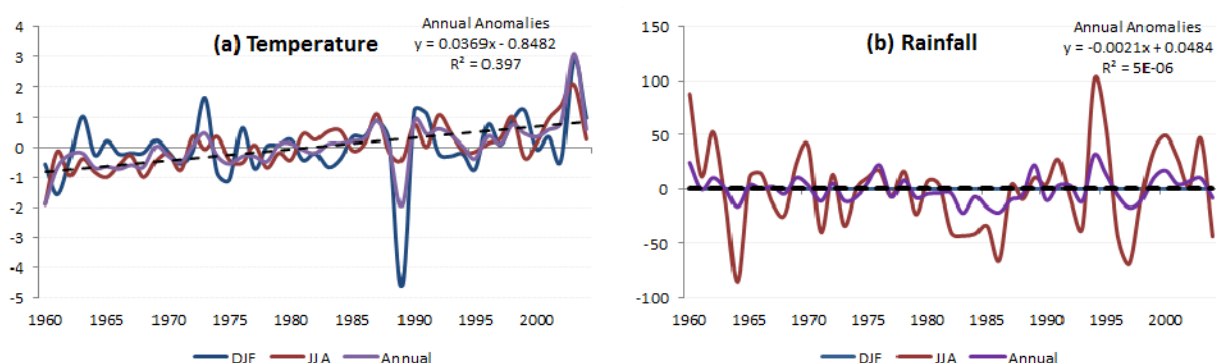
Drought episodes over the study area are used to estimate the effects of climate variability and change on the vulnerability of food crop production. While it is acknowledged that Africa's Sudan-Sahel experiences numerous episodes of drought and floods every decade, droughts are more frequent and contribute more significantly to agricultural losses in the region [15]. The Palmer Drought Severity Index (PDSI) for the Maroua-Salak meteorological station is used to identify periods of drought over the region in the time-series. The PDSI uses the bucket-type water balance model to compute the departure of soil moisture balance from normal conditions [16]. A more detailed methodology for the computation of PDSI can be found in Dai *et al.* (2004). The data developed by Dai *et al.* (2004 and 2011) classifies drought severity into six categories: -4.0 or less for extreme drought; -3.0 to -3.99 for severe drought; -2.0 to -2.99 for moderate drought; -1.0 to -1.99 for mild drought; -0.5 to -0.99 for incipient dry spell; and 0.49 to -0.49 for near normal conditions [16,17]. PDSI data is supplemented with reports of observed drought in the study region [18].

4. Results

4.1. Trends in Temperature and Precipitation

An observation of seasonal and annual temperature anomalies shows a steady and significant rising trend between 1960 to 2008 (Figure 2a). With the exception of an exceptionally low dry season mean temperature in 1989, there is no distinction between the trend of temperature change between the rainy and dry seasons. Unlike temperature, precipitation trends reveal no general long-term seasonal or annual trends (Figure 2b). The precipitation data reveals incidences of recorded drought episodes that affected Cameroon's Sudan-Sahel, such as those of 1983–1985, 1987, 1992 and 1997 [18]. While evident in the data, the more widespread drought that affected large swaths of the African Sudan-Sahel does not leave as big a mark on the time-series as much as more localized drought episodes (Figure 2b). The precipitation data also reveals greater inter-annual variability in the decade of the time-series.

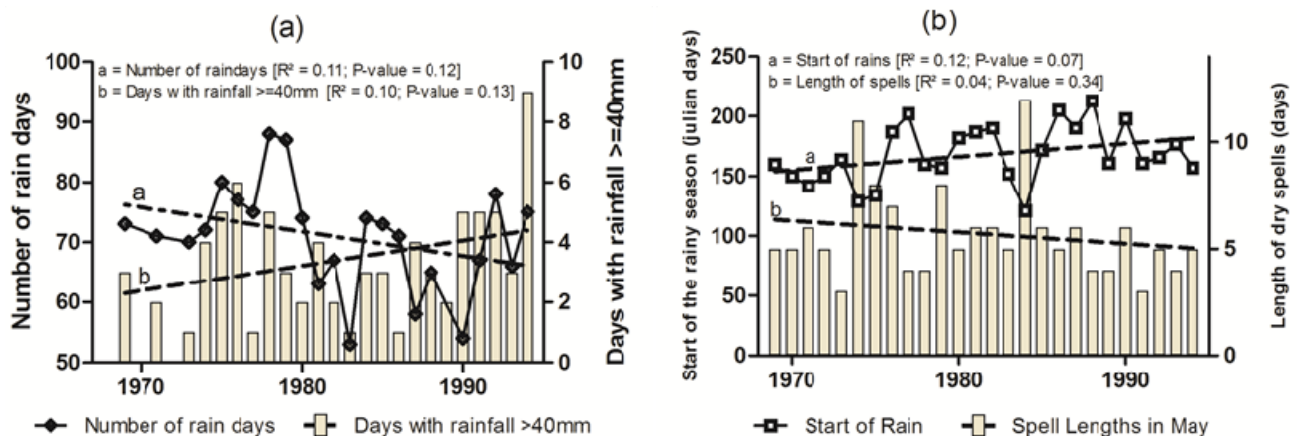
Figure 2. Seasonal and annual temperature and rainfall anomalies for Maroua-Salak.



Rainfall plays a very important role in agricultural production in the Sudan-Sahel. It has even been estimated that a reduction of about 10% of seasonal rainfall can translate to about a 4.4% decrease in a country's food production [19]. Before rainfall translates to food production, however, the rain water is acted upon by a number of environmental processes, such as surface runoff, infiltration and evapotranspiration. These processes depend on a wide-ranging number of environmental factors.

Evapotranspiration, for example, which is a considerably important factor of crop production, depends heavily on sunshine, temperatures at the surface of the ground, temperature at the lower atmosphere over the surface, winds and other factors [20].

Figure 3. Trend in number of rain days and days with daily rainfall ≥ 40 mm (a) and trends of start of the rainy season and length of dry spells (b).



While the general trend of rainfall remains relatively unchanged since the 1960s (Figure 2), there is a non-significant trend of rainfall falling increasingly unevenly in larger events (Figure 3a). The number of days of high rainfall also shows a statistically insignificant increasing trend (Figure 3a). The number of days of rainfall gives an impression of the distribution of rainwater inputs within the cultivation season. The number of days of abnormally high rainfall gives insights on the propensity of floods, soil erosion, the infiltration of rainwater into the soil, crop damage from falling raindrops and winds that usually accompany intense rains in this agro-ecological zone. These are precipitation characteristics that have the potential of affecting crop production in the Sudan-Sahel [21]. From a farmers' perspective, besides damaging crops on farms and reducing soil fertility, increasing rainfall intensities can also damage crops during storage at home, as well as limit access to farms for the delivery of farm products. In recent years, studies have reported cases of flood-related damage to crops at different levels of the production and distribution chain, with disastrous outcomes for smallholder farming households and farming communities in Africa's Sudan-Sahel [10,22].

While dry spells are an inherent characteristic of arid and semi-arid climates [23], research has identified changes in the start of the rainy seasons and probable increases in the length of dry spells as some of the agro-climatic challenges that farmers in the Sudan-Sahel of Africa may have to cope with in the future [21,24]. Changes, such as the time of cessation of the rainy season, the length of dry spells and the start of the rainy season, have been reported to be significant in parts of Cameroon [25–27]. The data from the study area does not, however, show any significant trends of changes in either the start of the rainy season or the length of dry spells (Figure 3b). One must note, though, that while the daily data provides a useful understanding of the 25-year period between 1969 and 1994, this analysis would have benefited from better insights if daily data for the last 18 years were available.

4.2. Trends in Crop Production and Area Cultivated

The trend of food crop production is variable for different crops. Maize and cowpeas production has been increasing significantly over the time-series (Figure 4). The production of all sorghum crops, as well as groundnuts, has remained relatively unchanged, while millet has been falling steadily. The increase in maize production can be attributed to the high demand for the crop, partly fuelled in recent years by industrial demand from breweries. This has made maize production an important activity both for food production and income generation. This has been at the expense of millet, whose net income per unit area cultivated is small compared to maize and whose demand is limited to local consumers. Cowpeas have increasingly been important not only as a locally consumed vegetable, but also as a source of soil nitrogen enrichment for local farming systems. Their importance as a soil enrichment source gained prominence in the early 1990s, when state-subsidized sources of cheap fertilizers were restricted. Sorghum remains a local staple food crop and a base for the manufacture of local beverages, while groundnuts remain the most favorable traditional income-generating crop for small-scale farmers cultivating on sandy soils.

The most important aspect of food production trends, as seen in Figure 4, is the close relationship between the amounts of area cultivated and total production. The cultivated area for different crops has grown, while production intensity has not. The correlation between total production and total area cultivated of all individual crops is statistically significant at $\alpha = 0.05$ (Figure 4). Changes in total production over the years are overwhelmingly an outcome of the amount of area cultivated, not the outcome of increases in yields per hectare. In the Sudan-Sahel agro-ecological zone with the highest population density in the country, this trend poses serious challenges for the future of food security. Sustaining food production in the future with increased competition for land (driven by demography and urbanization) may become increasingly more challenging.

4.3. Rainfall Variation and Yields

Notwithstanding the importance of rainfall in food crop production in the Sudan-Sahel, the proportion of variation in crop yields that can be explained by variations in total rainfall amounts (R^2) is generally small (Table 1). The exception to the limited contribution of rainfall to total yield variation is with sorghum (dry season). This is understandable, because this crop is planted towards the end of the rainy season. It depends on sufficient water falling at the tail end of the rainy season to establish itself. A fall in the total amounts of rainfall during the rainy season, therefore, has the potential of severely affecting the crop [28]. The correlation (strength of relationship) between crop yields and rainfall is moderate for millet and sorghum and generally weak for the rest of the crops (Table 1).

Figure 4. Total production of crops studied (in thousand tons) and total area cultivated (in thousand hectares) 1984–2005 in the Far North region of Cameroon. The data used to develop this figure is derived from FAOSTAT (2012).

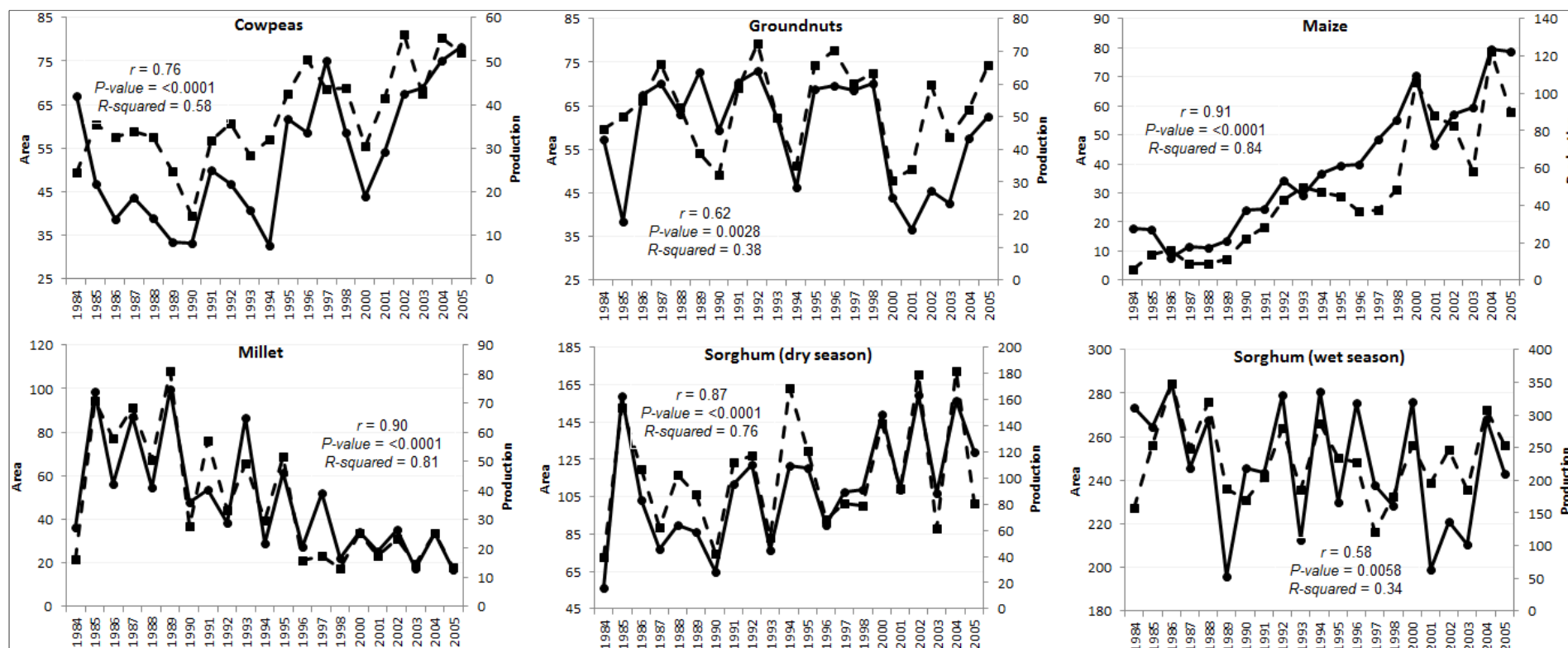


Table 1. Regression of total annual rainfall to yields of major food crops in Cameroon's Sudan-Sahel.

<i>Crop</i>	<i>Statistic</i>			
	<i>R-squared</i>	<i>Correlation</i>	<i>Mean Square Error</i>	<i>P-value</i>
Cowpeas	0.08	0.28	0.97	0.2125
Groundnuts	0.04	−0.19	1.01	0.3846
Maize	0.03	0.17	1.02	0.4327
Millet	0.13	0.36	0.91	0.1116
Sorghum (dry)	0.28	0.53	0.76	0.0132
Sorghum (wet)	0.07	0.26	0.98	0.2515

The above results of the regression analysis do not discount the very important role played by rainfall in enabling agriculture and sustaining crop production in the Sudan-Sahel. The low amount of yield variation explained by rainfall on other crops may be associated by the relatively tough crop cultivation conditions of the Sudan-Sahel agro-ecological zone. The severely arid dry seasons means that when the rains begin, considerable amounts of the rain water have to be used up in getting the soil to a moisture level that can support planting. Before the soil reaches optimal levels to permit planting and crop growth, a lot of the precipitation is lost to evaporation and surface run-off on the sparsely vegetated land [29]. While this portion of the rainfall contributes in building up enabling conditions for cultivation, it does not directly contribute to plant growth, biomass accumulation and yield improvement. Crop pests and diseases are a contributing feature to the tough crop production conditions in this agro-ecological zone [30] and contribute to yield losses for many food crops. Within the rainy season, agro-climatic events, such as dry spells, can reduce the viability of plant growth and contribute to low yields [27,28]. The dominant natural vegetation of this agro-ecological zone is open grassland and sparse shrub land [29]. As a result, the soil is generally less protected from erosion by wind during the dry season and sheet erosion in the early rainy season. This reduces the quality of the top soil and reduces crop water use efficiency. The quality of seeds for food crops cultivated in this agro-ecological zone has not been bred to fully withstand many of the above constraints. The above constraints point to the important role policies and management play in determining yields or food production in this agro-ecological zone. This can be further demonstrated by an observation of the effects of government intervention on the rainfall-crop yield time-series (Figure 5).

4.4. Effects of Support for Agriculture on the Rainfall—Crop Yields Time-series

Structural adjustment is a set of measures undertaken with the goal of permitting renewed, or accelerated, economic development by rectifying ‘structural’ disequilibrium in the foreign and public balances [31]. Between 1960 and 1985, Cameroon's economic growth was based on development of the agricultural sector [32]. In the late 1980s and 1990s, a number of macro-economic conditions led the government of Cameroon to accept the implementation of the SAPs under the direction of the World Bank and International Monetary Fund. Key among these conditions was a decline in the terms of trade for crop exports, which contributed a large share of the country's gross domestic product. This situation was aggravated by the fact that most of the income from exports was expressed in US dollars, of which the price against the CFA franc dropped by about 40% after June 1985 [32]. The result was

a slowdown of the economy, with serious deficits arising in public finance and the balance of payments [32]. The SAP strategy for reforming the economy entailed making it more productive and competitive. With regards to agriculture, the new policy, stressing on liberalization, privatization and diversification, was initiated in the 1990/1991 agricultural season [32]. On the ground, this meant closing down hitherto state-subsidized companies, agricultural price stabilization schemes and a number of agricultural extension schemes, which provided local level guidance on a wide range of agricultural production enterprises. Through the implementation of the SAPs, small-scale farmers were therefore deprived of a wide range of government-assisted support services offered by agricultural extension workers and technicians on the government payroll. Pre-SAP, the government of Cameroon also provided material support for agriculture through the subsidization of farming inputs, such as fertilizers, seeds and pesticides, as well as proactive policies of soil conservation and agricultural innovation through local, international institutions and extension services [33]. This support also suffered serious curtailment as a result of the implementation of SAPs [32]. Hence, the period before the strict implementation of the SAPs (before 1989) was marked by significant support of agriculture at the local level, while the period of strict implementation of the SAPs (1990–1999) saw these support structures and services largely dismantled. Since 2000, the government has been making efforts at supporting agriculture through project-based support packages designed to address specific challenges at different levels of food production [34,35].

Figure 5 and Table 2 present the results of the examination of standardized yields per hectare and total rainfall time-series. In Figure 5, a clear mismatch exists between total rainfall and crop yields for at least five of the six crops in the period 1984–1989 (the mismatch is less obvious for maize). This mismatch is far less evident for the period 1990–1999 (color-coded in orange). From 2000, the mismatch is not as evident as it is in the 1990–1999 period. The period before 1989 shows standardized yields generally above rainfall. This is the period prior to the introduction of the Structural Adjustment Programmes (SAPs) in Cameroon. During this period, government support for agriculture was proactive and enabled farmers to achieve production levels above those constrained by one of the major biophysical impediments to food production (rainfall) in the region.

Table 1 presents the results of correlation tests between crop yields and periods of different levels of governmental support for agriculture in Cameroon's Sudan-Sahel. For the period 1984–1989 (when government support to agriculture was still substantial), the strength of correlation between total rainfall and yields is less than that of the period 1990–1999 (when the SAPs were being firmly implemented) for four out of six of the crops. These crops are dry and wet season sorghum, millet and cowpeas (Table 2). The time-series shows a stronger correlation of rainfall and crop yields during the period 1990–1999 (Table 2). This suggests that with the absence of governmental support, agriculture tended to be an event-driven system, in this case, driven by rainfall (one of the main variables on which food crop production in this region relies). In the period after 2000, the strong correlation observed in the preceding period (1990–1999) is shown to have been disrupted for four crops (wet and dry season sorghum, millet and cowpeas, in Table 2). This seems to suggest that emerging governmental efforts at supporting food crop production have the potential of changing agriculture from being a highly event-driven activity to one that draws on an integration of both human and natural resources.

Figure 5. Standardized total annual rainfall anomalies and standardized yields per hectare for selected food crops in Cameroons Sudan-Sahel agro-ecological zone. The time segments indicating periods with different levels of intervention in agriculture are color-coded: blue = the pre-SAP period (up to 1989), characterized by comprehensive assistance to agriculture; orange = period of the firm implementation of SAP (1990–1999); green = period when the government resumption of assistance to agriculture became more widespread (from 2000).

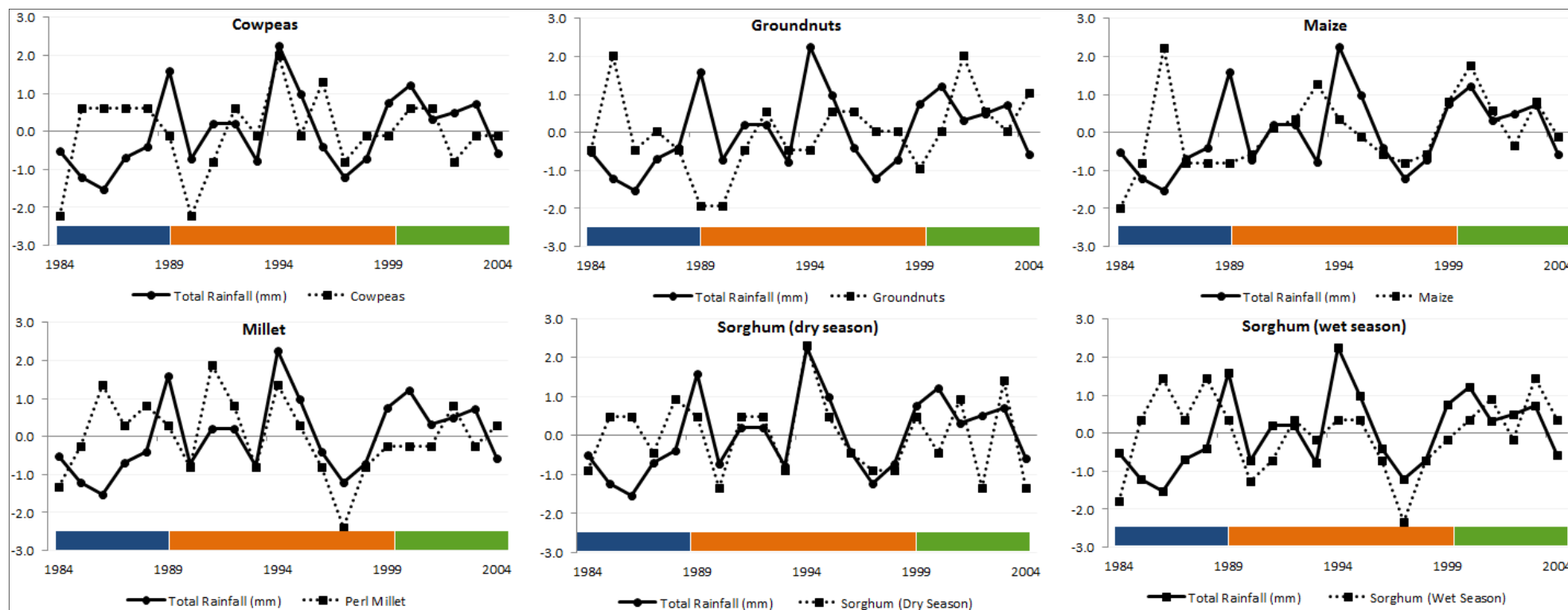


Table 2. Results of test for correlation (r) between total rainfall and crop yields ($\alpha = 0.05$) in the period before the full implementation of SAP (1984–1989), the period of dedicated implementation of SAP (1990–1999) and the period when governmental efforts towards support for agriculture were reinstated (after 2000).

Crop	Period	Statistic		
		r	P -value	R^2
Cow Peas	1984–1989	−0.21	0.6868	0.045
	1990–1999	0.59	0.075	0.34
	2000–2004	0.26	0.6701	0.069
Groundnut	1984–1989	−0.73	0.1016	0.53
	1990–1999	0.071	0.8463	0.005
	2000–2004	−0.55	0.3353	0.3
Maize	1984–1989	−0.4	0.4281	0.16
	1990–1999	0.38	0.2785	0.14
	2000–2004	0.74	0.1508	0.55
Pearl Millet	1984–1989	−0.12	0.8231	0.014
	1990–1999	0.73	0.0162	0.54
	2000–2004	−0.4	0.5071	0.16
Sorghum (dry)	1984–1989	0.085	0.8732	0.0072
	1990–1999	0.95	<0.0001	0.9
	2000–2004	0.38	0.532	0.14
Sorghum (wet)	1984–1989	−0.14	0.7917	0.02
	1990–1999	0.74	0.0151	0.54
	2000–2004	0.11	0.8626	0.012

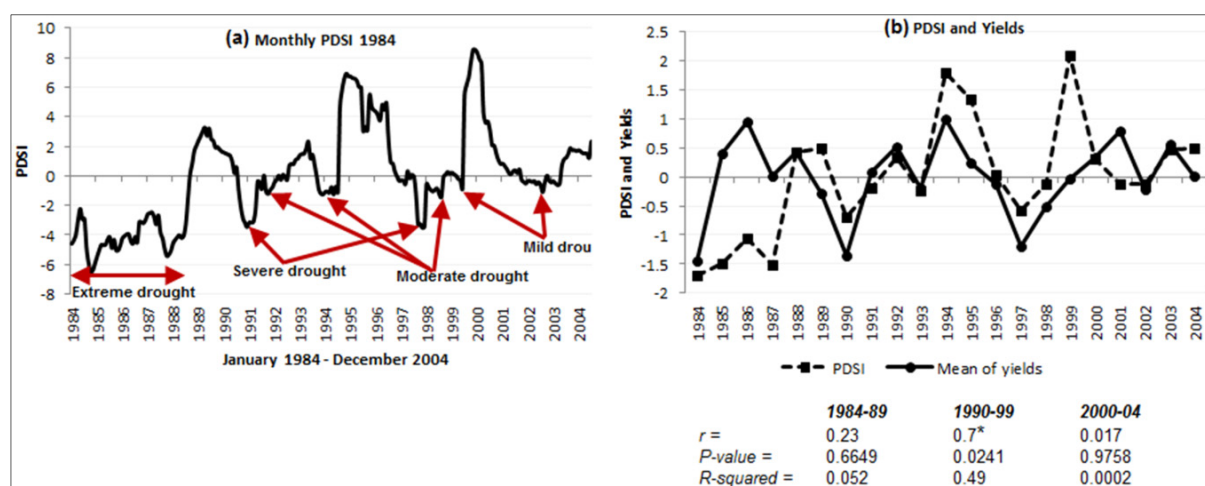
Between 1995 and 2000, the region experienced two major episodes of food price increases, which may have forced the government to rethink the strictness of its implementation of the SAPs. The earliest efforts at revising agricultural support policies and implementing efforts that would increase agricultural production began in the late 1990s [33–35]. These efforts have increased over the years. At present, neither all crops nor all agricultural production systems are supported. Some support programs do not even cover the entire country. On the time-series, the effects of these efforts are evident, albeit subtle, since 2000 (Figure 5). The effect on the time-series is clearer for crops such as wet season sorghum and groundnuts in which support programs are already being implemented in the study area and less clear for millet, cow peas and dry season sorghum, where assistance is limited. It must be noted, too, that it is less clear for maize, even though this crop is already receiving support in the region.

4.5. Climate Extremes, Yield Vulnerability and the Effects of Support for Small-scale Agriculture

Between 1984 and 2004, the study region experienced several years of drought (Figure 6). Some of the drought episodes, as well as their effects on regional hydrology and livelihoods, have been recorded and reported [18,25]. A correlation analysis computed for mean standardized crop yields on standardized PDSI over the entire time-series (1984–2004) gives a correlation of 0.38. This indicates that the association of yields to droughts in the correlation model is 38%. By comparing yields over the time-series with a history of state intervention in agriculture, one again finds that during the years of

government support to agriculture (1984–1989), drought had less impact on yields than in years of less or no support (from 1990–1999). The correlation between PDSI and the mean of crop yields is statistically significant for the period 1990–1999 and is not for the period before or after this (Figure 6). In the absence of support, yields are therefore strongly associated to climatic shocks, such as droughts.

Figure 6. Drought incidences 1984–2004 and their correlation with the mean of standardized yields in Cameroon's Sudan Sahel. Data for the figures is derived from Dai (2011).



In the 1984 drought, farmers and the government were caught off-guard by unusually long periods of dry spells, which destroyed crops and yields that were already planted. In the time-series, the yields in 1984 were affected notwithstanding the existence of government support schemes (Figure 6). In subsequent drought years (up to 1989) when support for agriculture was sound, government response was instrumental in shielding yields from the effects of droughts. Support took the form of more comprehensive advice on planting dates through meteorological forecasts, advice on appropriate locations for cultivating specific crops and the usual support in subsidized seeds, fertilizer, pesticides and farming credit. As a result, standardized yields remained well above PDSI throughout most of the drought years (Figure 6). During the period of devoted implementation of the SAPs in 1990–2000, the effects of the droughts of 1990, 1992 and 1997 are more evident on crop yields. The decline in crop yields and resulting food production resulting from these droughts may be explained by the heavy dependence of farmers on nature (rainfall in this case) with little or no cushioning for climatic shocks. Such heavy dependence on rainfall in sensitive agro-ecological zones, such as the Sudan-Sahel, leaves farmers vulnerable and threatens food security.

5. Discussion

5.1. The Importance of Reconsidering Agricultural Water Management Strategies in Africa's Sudan-Sahel

The importance of rainfall in determining crop yields, as illustrated in Figure 5 and Table 2, has to do with the reliance of crop production on rainfall as the dominant source of agricultural water in the Sudan-Sahel. Such reliance is reinforced by the low development of irrigation infrastructure in this part of the world. Also, the level of development of water harvesting, storage and utilization systems

remain poor. Developing sustainable and optimized systems of agricultural water harvesting, storage and utilization could go a long way in reducing the vulnerability of small-scale farmers. In agro-ecological zones with water-constraint crop production, such as Africa's Sudan-Sahel, optimizing these systems and technologies can play an important role in improving agricultural productivity. This is all the more important because of the frequency of intra-seasonal moisture-deficits that are associated to crop failures and low yields of food crops [36]. To achieve higher levels of crop water use efficiencies, deliberate steps must be taken to develop and implement better on-farm water management strategies. Besides improving crop yields [37,38], improving crop water use efficiencies can come with a host of benefits with regards to soil health, catchment water balance, agricultural biodiversity and the attainment of food security [39–41]. Successful schemes of this kind in Burkina Faso, Kenya, Niger, Sudan and Tanzania show increases in yields of a factor of 2 to 3, compared with dry land farming systems [42], with far-reaching positive consequences on livelihoods [43]. Besides improving farm-water management strategies, the improvement of associated rural and urban food linkages is needed to translate increased water use efficiencies to food security improvements. Such key linkages in Africa's Sudan-Sahel are farm-to-market roads, the agricultural input linkage between manufacturers and farmers, information linkage systems between agricultural extension workers and small-scale food producers and market information linkages on supply and demand for food commodities in local and regional markets. The resources required to develop and sustain these linkages, as well as the associated infrastructure required to translate increased productivity into food security, are generally beyond the reach of most small-scale farmers in the region [43].

5.2. Planning for Climate-induced Vulnerabilities to Food Crop Production

The close correlation of crop yields with rainfall (Figure 5 and Table 2), as well as the frequent occurrence of rainfall related accidents (Figure 6), also warrants proactive planning against climate-induced crop production vulnerabilities. Such planning may be designed to provide farmers with a range of resources, such as agro-climatic early warning information, optimal crop-choices based on seasonal agricultural water-balance forecasts and weather-related crop failure insurance schemes. Such planning calls for a more active use of agro-climatic and food security forecast products as a planning tool by regional and national food security institutions. Products, such as Global Information and Early Warning System (FAOGIEWS) of the United Nations Food and Agricultural Organization and United States Agency for International Development Famine Early Warning Systems (USAID-FEWSNET), are developed specifically for such uses and can be accessed using relatively affordable technologies by regional and national food security planning institutions. It must be noted though that concerns have been raised on the potential of such systems being used by merchants and bankers to speculate on food prices, which may defeat the purpose for which they are put in place [23]. Improving on food utilization by minimizing waste and increasing training on nutrition needs for different populations of the community can ensure optimal exploitation of food resources. The link between food security and weather-risk management has been established [44], and studies have identified the role that indexed-based (especially weather-indexed) agricultural insurance schemes can play in meeting the goals of food production and livelihood protection among food producers in low income countries [45,46]. Providing an enabling framework for the development of crop failure insurance schemes is therefore

being urged as one of the tools that has the potential of increasing farmers' adaptation potential and increasing resilience to global environmental changes [44,45,47]. While index-based crop insurance schemes promise some benefits, a number of implementation challenges may have to be overcome for these systems to be viable as business opportunities for investors.

5.3. Implications for Food Security Vulnerability in the Sudan-Sahel

The close correlation between yields and rainfall in the absence of support for agriculture (Figure 5 and Table 2) warrants an examination of the effects that climate change may have on food security in the Sudan-Sahel. The link and importance of climate (especially rainfall) in the Sudan-Sahel has been made by previous research [10,23,26]. Notwithstanding the ability for global climate models in predicting seasonal variability over the Sahel, very little consensus exists on climate change projections (especially with regards to future precipitation trends). Most models, however, agree that for the west-most Sahel, there will be a significant decline in annual precipitation and, at the same time, an increase in annual precipitation in the eastern Sahel, around eastern Ethiopia [48]. For the area around Lake Chad, which covers north Cameroon, Nigeria, Chad and neighboring countries, there is not yet a consensus on the direction of future precipitation change [48]. Irrespective of the future direction of precipitation change, it is important to stress its close correlation with yields and the effects of support in buffering small-holder producers from shocks related to annual variability (Figure 2b) or sporadic events (Figure 6). Unlike precipitation, the trend of temperature change in the region seems to be unambiguous (Figure 2a).

While the effects of climate change may be beneficial for food crop production above latitude 55°, where warmer temperatures may extend the growing season, in most parts of the developing world (especially sub-Saharan Africa), the projected increases in temperature and changes in patterns of precipitation are likely to have a negative impact and will further complicate the achievement of food security [49]. The key requirements for the attainment of food security have been defined as enabling availability, access, utilization and stability of food resources [5,50]. Climate change and variability is expected to affect the biophysical agricultural production potential in tropical and sub-tropical countries [50–53], which can directly affect the availability component of food security in the region. This is especially so, because of the large number of farmers who depend directly on food from their farms for a large proportion of the food they consume. Climate change also has the potential of affecting other non-agricultural livelihood activities on which households depend. In the Far North Region of Cameroon for example, fishing from Lake Chad has for several centuries been an important source of dietary protein and non-agricultural income for many of the communities in the region. The drying up of Lake Chad, partly attributed to climate change, has significantly reduced this food and income source [18]. Income can enable people to access food when they are unable to produce it themselves or when there is the need to make up for their deficits in production. A decline in income, therefore, affects people's ability to access food. It must be noted that while many farmers in traditionally agricultural societies may meet a majority of their food needs in the best cases, it is highly unlikely that any household would meet their totality of needs. In the very best case scenario, a majority of farmers would still need some form of resource (money or otherwise) to purchase a

proportion of their food needs. These needs may be different with different communities. In Cameroon's Sudan-Sahel, food essentials, such as salt, cooking oil and sugar, have to be bought.

6. Conclusions

Rainfall is an important climatic factor that provides enabling conditions for crop production in the Sudan-Sahel agro-ecological zone of Africa. Incidences of rainfall failures have the potential of affecting yields and production of food crops in the region, with far-reaching outcomes to the food security and livelihoods of small-holder farmers in the region. Support for agricultural production can make a difference in regions where environmental constraints impact food production. Key areas of support to buffer the effects of climate variability in the Sudan-Sahel would include the development of better strategies for agricultural water management and proactively planning for climate-induced vulnerabilities to food crop production. While there is still a lack of consensus on future precipitation trends in parts of the Sudan-Sahel, the importance of rainfall in the production of food crops in this region has been identified. Managing the challenges associated with climate variability and change would be essential in achieving the food security goals of the populations of this region.

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Conflict of Interest

The author declares no conflict of interest.

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