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Rain, temperature and agricultural production: The impact of climate change in Sub-Sahara Africa, 1961-2009

Andreas Exenberger[*], Andreas Pondorfer[#]

Abstract

This paper is about the effect of climate change on Sub-Sahara African (SSA) agricultural production in a post-colonial setting. While agricultural production certainly is the result of a multi-dimensional process (influenced by diverse branches of politics, by technology, and also by trade patters and violent conflicts, among others), already the partial analysis of the most obvious factors of influence is certainly valuable in the African case. Since agriculture is not only the single most important sector for the greatest majority of people there, but also a low-tech endeavor in Africa, the impact of temperature and particularly rainfall is crucial – to the point of life-threatening crop failure.

In sum, we are able to shown that climate change influenced agricultural production in Sub-Sahara Africa in an unfavourable way. When considering traditional and modern inputs (labour, land and livestock, as well as capital and fertilizer, respectively) in a fixed-effects-model, particularly the effect of rainfall is significantly positive and important. Further, by separating countries into a low- and a med-tech group (with respect to modern inputs), different relationships between the standard factors can be revealed, and by refining the specification with respect to regional climatic differences some complexities in these general patterns can be shown.

Keywords: Sub-Sahara Africa, agriculture, climate change, panel regression

JEL Classifications: N57, O13, Q54

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1 INTRODUCTION

In preparation of the Copenhagen Climate Summit in December 2009, a group of ten African leaders agreed on a resolution to pledge rich countries to pay US$ 67 billion annually "to counter the impact of global warming in Africa."[1] In Copenhagen then, while the actual proposal certainly had no chance to be considered seriously (and was even abandoned by some of it signees), also the leaders of industrialized countries recognized their responsibility and proposed milder versions of this kind of "compensation" – much milder with respect to amount and liability. Anyway, the issue will remain on the agenda, and while the reality of climate change is recognized more or less unquestioned in international political arenas (sometimes certainly for opportunistic reasons), the controversy moves to responsibility and compensation issues.

The impact of climate change on Africa is hardly deniable, not only for the present, but even for past decades. What makes things worse is the fact that Africa has only marginally contributed to the forces resulting in global warming but is at the same time particularly vulnerable to it. Generally, the African population is much more dependent on agriculture (for consumption as well as employment) than populations in other global regions, and furthermore, this dependence rests much more on low-tech, low-capital rainfall agriculture, in which climate rigor can barely be compensated for.

Consequently, this paper is about the effect of climate change on Sub-Sahara African (SSA) agricultural production in a post-colonial setting. While agricultural production certainly is the result of a multi-dimensional process (influenced by diverse branches of politics, by technology, and also by trade patters and violent conflicts, among others), already the partial analysis of the most obvious factors of influence in a low-technology environment is certainly valuable. Since agriculture is not only the single most important sector for the greatest majority of people in Africa, who are vitally dependent for their daily living on the products of their soil, but also – on average – a low-tech endeavor in Africa (low level of irrigation, high level of labor input), the impact of temperature and particularly rainfall is crucial. Further, the effects of anthropogenic climate change are easily observable in Africa, facing serious challenges, particularly from the second decade of formal independence on. While during the 1960s weather was generally favorable for agricultural production in Africa,

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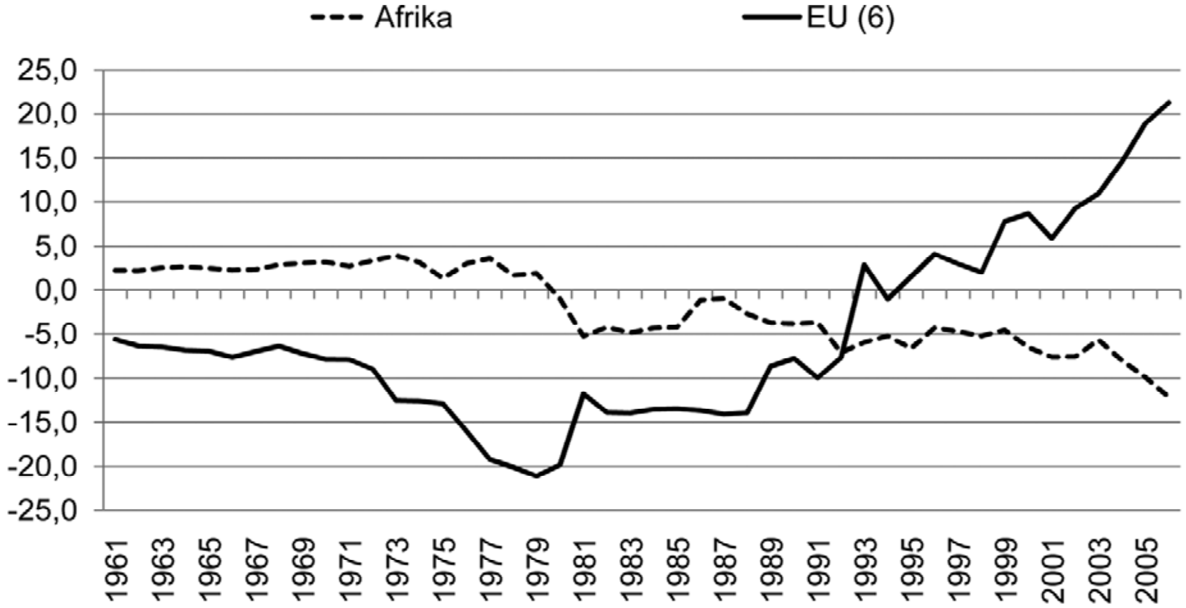
[1] Reuters, Aug 24, 2009; online at: http://www.reuters.com/article/2009/08/24/us-climate-africa-idUSTRE57N26M20090824.

it turned unfavorable in the 1970s and 1980s, regionally resulting in serious problems and sometimes virtual disaster. Combined with political ignorance, population growth and adverse effects in terms-of-trade-development, this resulted in a shift of the overall trade flow of agricultural products: Africa – as a whole as well as regularly on the country-level – turned from a food-exporting to a food-importing region, with expectable negative effects on food security.

A comparison between Europe (the EU-6, i.e. Belgium, Germany, France, Italy, Luxemburg and the Netherlands) and Africa clearly shows this structural change: while agricultural reforms in Europe boosted exports, particularly in the 1990s, Africa turned to an importing global region already at the end of the 1970s. It is also worth to note here that overall production figures of Europe clearly outpace the numbers for Africa.

Figure 1: Agricultural trade balance for Africa and the EU-6, 1961-2005 (in US$ billions)



Source: FAOSTAT

Further, overall improvements of food security are modest (with the exception of Northern Africa, which is a totally different story in many respects and hence excluded from this analysis) and subject to regional differences: while particularly Western Africa improved supply in the 1980s and 1990s, Eastern and Central Africa even faced downward trends.[2]

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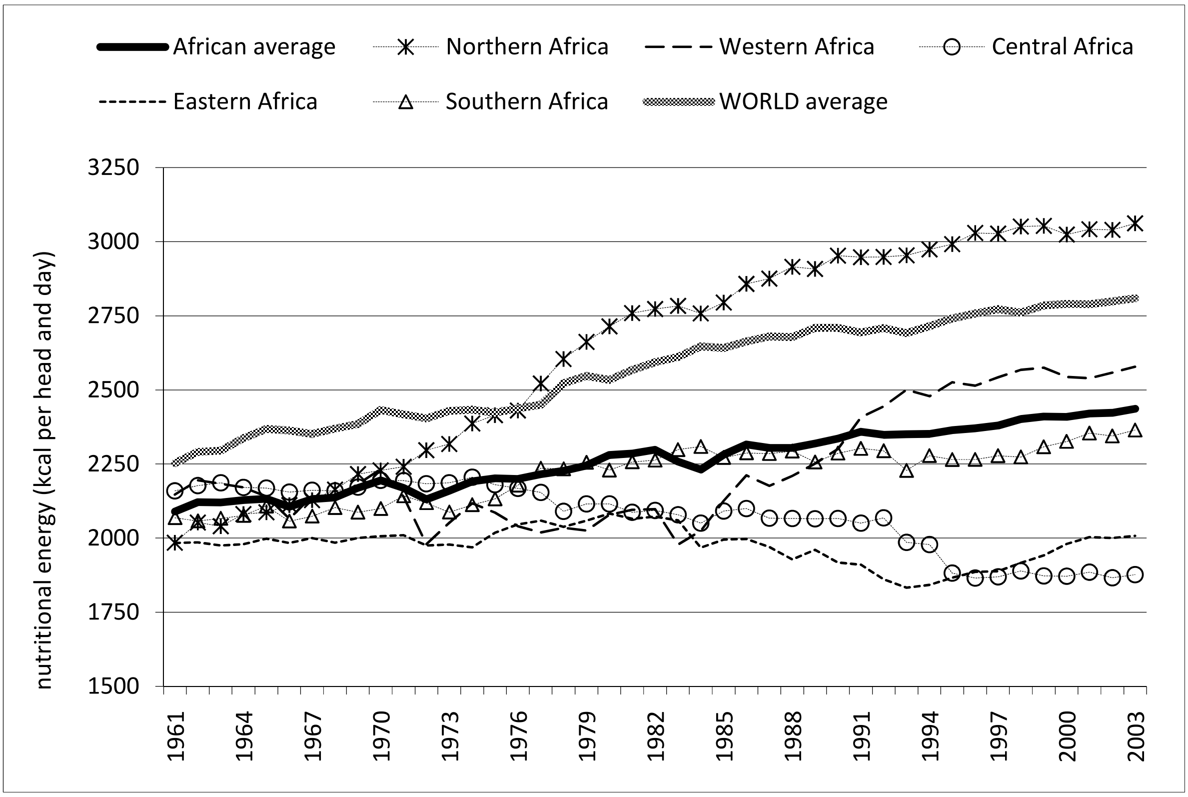
[2] It is worth to note here that a supply of 1,800 kcal per head and day are regarded the absolute survival minimum (given "light" physical work) and that these numbers reflect averages and do not consider food loss and waste.

Figure 2: Nutritional energy production (including trade balance) for African regions, 1961-2003

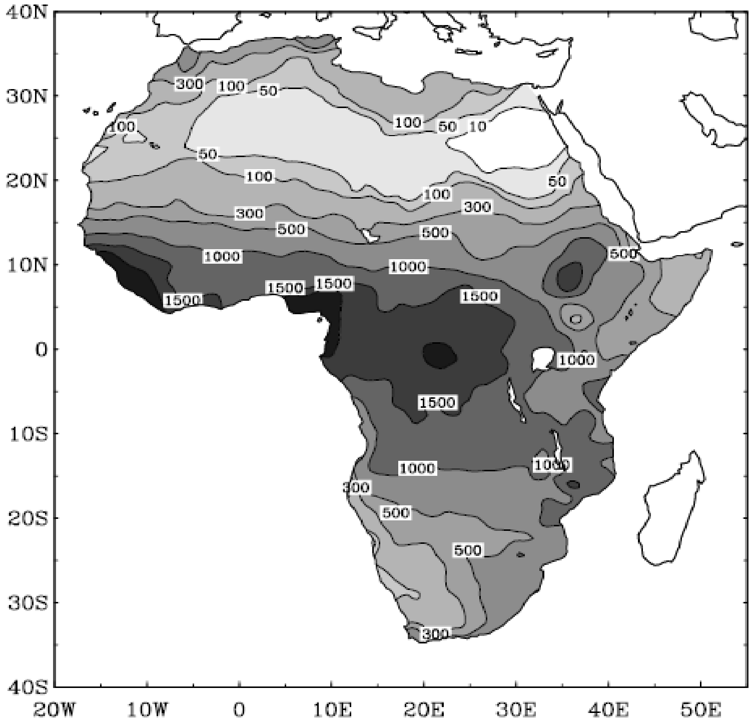


Source: FAOSTAT

2 BACKGROUND

Climatically, Africa is shaped by a basic pattern: stable temperature and rainfall in equatorial regions and increasing volatility of both north as well as south of the equator to the point of desertification – of course with regional variations and complexities (Adams et al. 1996, ch. 3-5; Strahler & Strahler 2006, ch. 7; Stock 2004, 77-79). More precisely, equatorial climates are characterized by heavy rainfall (of more than 3,000 mm per year, slightly higher in Western Africa) and a dry season that is either very short or missing, and temperatures are high, averaging about 25 °C. The tropics around the equatorial zone are humid throughout the year with less rainfall than the equatorial zone, generally about 1,000-2,000 mm per year. The rainfall tends to peak twice during the year, with the peaks separated by relatively short but distinct dry seasons. Annual variations in climate tend to be a little higher than in equatorial climates. Both regions cover 14 % of total surface land in Africa. Sub-humid regions (tropical wet and dry climates) are located to the north and south of the humid tropical zone and cover 31 % of total surface land. These regions are characterized by a lengthy dry season, typically five to eight months in duration. As distance from the tropics increases, duration and reliability of rainfall decreases. Precipitation generally averages between 500 and 1,000 mm per year. Consequently, dry climates dominate with 55 % of surface land. In these semi-arid (tropical steppe) and arid (desert) zones total annual evaporation of moisture from the soil and from plant foliage exceeds the annual precipitation, which amounts for less than 500 mm annually during a rainy season that lasts one to three months.

Figure 3: Mean annual rainfall over Africa (in mm)



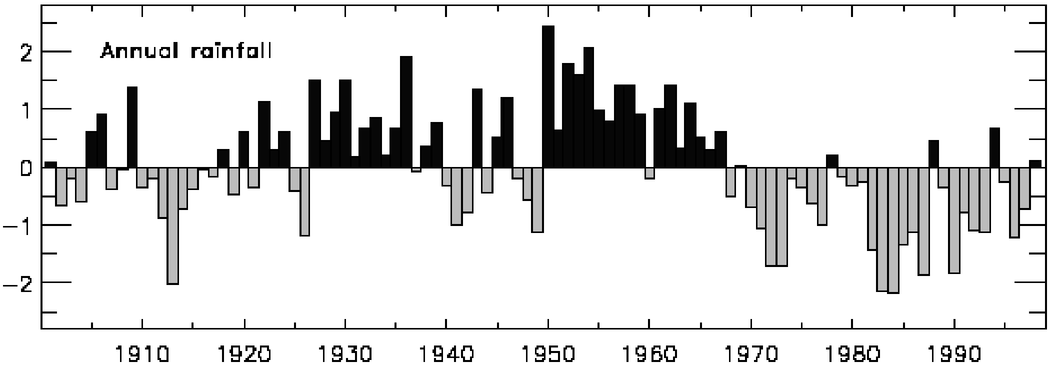
Source: Nicholson (2001)

Thus, while temperature is generally relatively favorable to agriculture in Africa, rainfall is modest compared to other global regions and consequently very likely – given the low level of irrigation in Africa – to exert an important influence on agricultural output. Consequently, there has been little interest in analyzing temperature patterns in Africa because of the overriding role of water. But there is increasing evidence that temperature controls important physiological processes in insects, plants and crops (Abrol et al. 1991; Challinor et al. 2006; IPCC 1995) and hence also this has to be regarded as a critical factor.

Concerning temperature, Hulme et al. (2001) show that warming over the 20th century has been at the rate of about 0.5°C per century (again with regional differences, including cooling in some regions, but also more than 2 °C in some other). Little larger warming occurs in the June-August (JJA) and September-November (SON) seasons than in December-February (DJF) and March-May (MAM). The six warmest years in their data series have all occurred since 1987, with 1998 being the warmest year. Patterns and amount in Africa are in line with global observations.[3]

Anyway, most studies still focus on precipitation. Inter-annual rainfall variability is large over most of Africa and for some regions, most notably the Sahel, multi-decadal variability in rainfall has also been substantial (Nicholson 2001). Generally, the early 20th century was rather dry (except for equatorial East Africa and the extreme North and South), the 1920s and 1930s were favorable (the least in southern Africa), and the 1940s rather dry again (particularly in West Africa).

Figure 4: Annual rainfall anomalies in the Sahelian zone (in standard deviations)



Source: Brooks (2004)

From the 1950s on fluctuations became even more pronounced, when river flow increased notably in the semi-arid regions and general conditions became favorable again. They even improved in the 1960s, particularly in the tropics, when also the level of Rift Valley lakes rose (Farquharson & Sutcliffe 1998; Nicholson & Yin 2001). From then on, conditions became worse, and particularly in the early 1970s and the early 1980s even disastrous in some regions. Generally, aridity became more widespread (rainfall decreased by 20 to 40 % in Sahelian West Africa, and generally by 5 to 10 % across the rest of the continent) and rainfall

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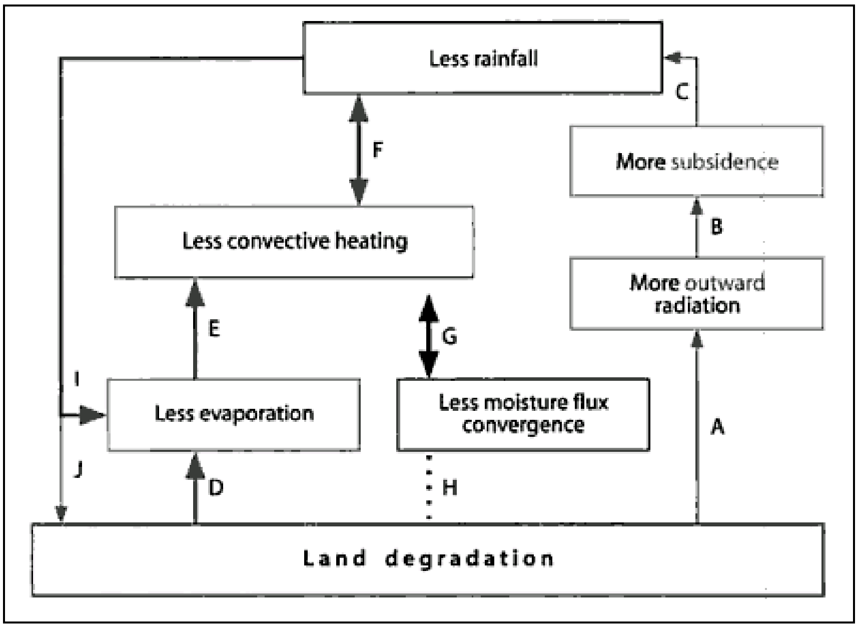
[3] For further details about long-term temperature changes see Jones et al. (1986, 1999), IPCC (1995), Nicholls et al. (1996), Hulme (1992) and Jones & Lindesay (1993).

remained below the long-term mean over most of Africa (Nicholson 1994, 2001), with southern Africa being an exception in case.[4]

Figure 5: Diagram of land surface degradation interactions and feedback processes



Note: The dark lines represent the main process. The dashed line between the surface and LMF indicates the uncertainty of their interaction

Source: Xue (2004)

Consequently, drought is a serious and complex problem for many African countries. For example, the favorable conditions during the 1950s and early 1960s resulted in a rise of human and especially animal population with an extension of the grazing land toward the north. Farming areas spread out from the Sahelian to the Saharo-Sahelian ecozone. When the first harvest and grazing failures occurred at the end of the 1960s, pastoralist and farmers rushed toward the south and fabricated a dangerous concentration of livestock and population across the 600-mm isohyet. Consequently, in the following years the mortality of livestock and people increased dramatically (Mainguet 1991). Also the long term impacts of the Sahel drought in the 1980s become clearer, which have sustainably influenced the vegetation cover. This permanent loss of vegetation would permit drought conditions to persist (Wang & Elthahir 2000). Precipitation directly affects vegetation, which in turn regulates spatial and temporal appearance of grazing and nomadism (Sivakumar 2007).

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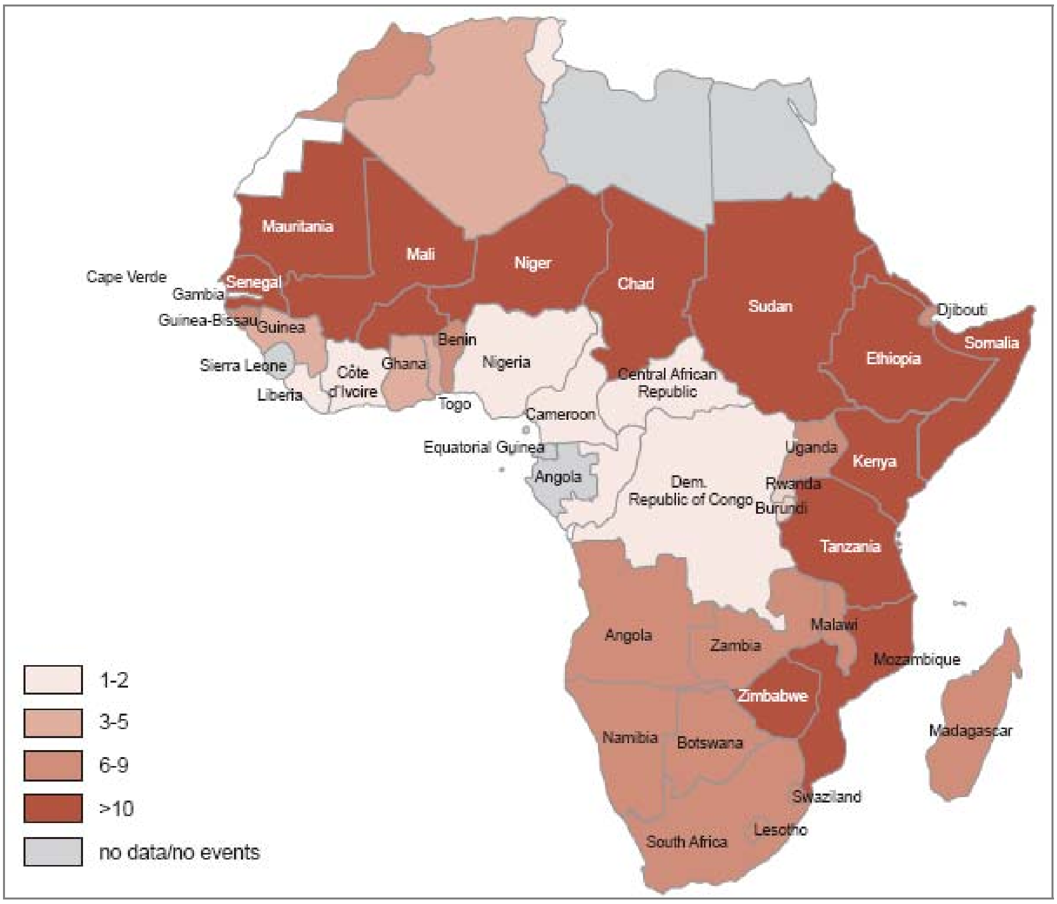
[4] This is mainly due to lower precipitation in July and August, while the average length of the rainy season has not changed significantly during the dry period 1970-1990 (Le Barbé & Lebel 1997).

Generally, the continent has witnessed a high frequency of occurrence and severity of drought. Extended droughts in certain arid lands of Africa have also initiated or exacerbated desertification (UNESCO 2007). This is particularly important due to their self-enforcing effect (Xue et al. 2004), also (negatively) affecting rainfall. In effect, once there is a lack of vegetation cover in an already fairly arid region, it stabilizes its own aridity in a vicious cycle: the high reflectivity of the surface, caused by lack of vegetation, would produce a dry climate which would not support vegetation, ensuring high reflectivity of the bare surface (Adams 2007).

Figure 6: Drought events per country in SSA from 1970 to 2004

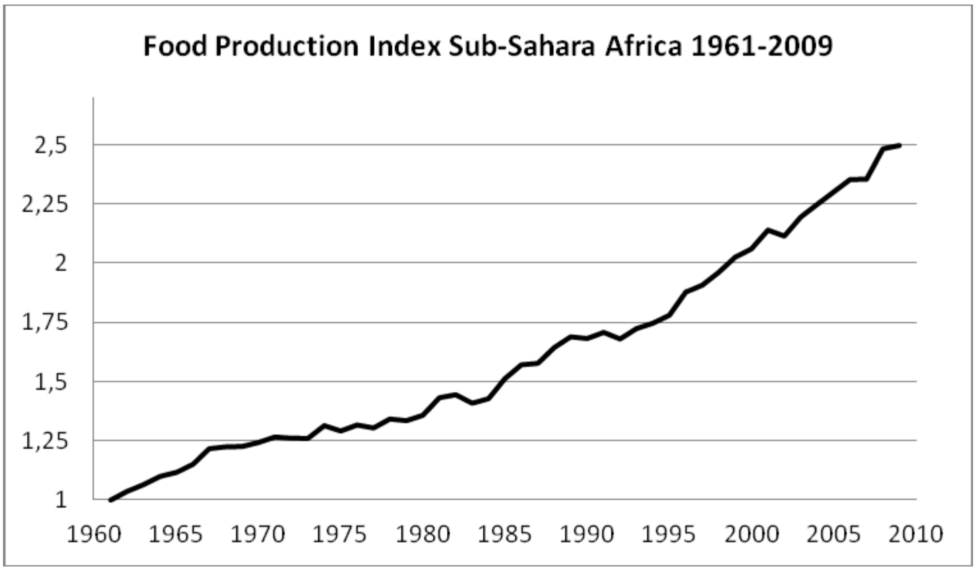


Note: Angola is found twice in this map, the more northern country is actually Gabon.

Source: Noojin (2006)

The agricultural environment in Africa has already been summarized as low-tech, labor-intensive, capital-scarce rainfall agriculture. Generally it is clearly a living “on the margin”. Further, rural agriculture was hardly subject to specific measures of political promotion because post-colonial states usually focussed on nation-building and hence on economic modernization (focus on industrialization) and political stabilization (focus on the urban space), while using traditionalism only as a vehicle for symbolic legitimacy. Agriculture was regarded as outdated and food security could not claim priority over gaining revenue from external trade. Consequently, agriculture was generally neglected and not developed, at least until the 1990s. Even more, when agricultural production was promoted, it was export production usually provided by monocultures and hence ill adapted to local conditions (natural as well as technological and economic), while the rural population was forced to overuse land and other resources for simple survival. Hence it will not come as a surprise that net agricultural production in SSA rose only moderately from 1961 to 2009, particularly in the first part of this time period.

Figure 7: Normalized Food Production Index in SSA, 1961-2009 (1961 = 1)

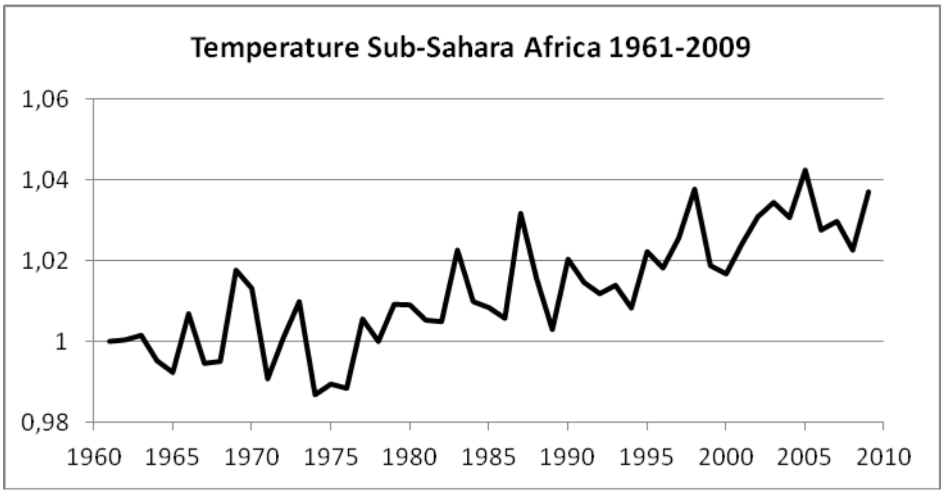


Source: FAOSTAT

Agricultural production has been constantly rising over the whole time period, except for the immediate aftermath of the two oil crisis, when it sometimes even declined in absolute terms. However, this increase by a factor of only 1.5 until the mid-1980s and by 2.1 until 2000 is clearly outpaced by population growth: the number of inhabitants rose from around 230 million in 1961 to about 500 million in 1990 and about 660 in 2000, hence per capita production decreased until the late 1980s. This is the backside of the trade-balance evidence provided above, that Africa turned into a food-importing global region around 1980.

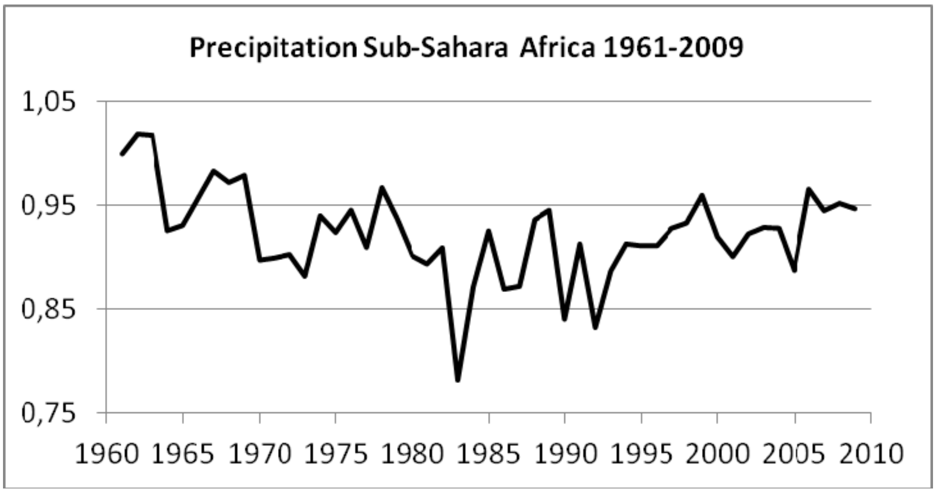
Further, average data about the observed climate variables – surface temperature and precipitation – have the expected trends: temperatures, although relatively volatile, tend to rise, and increasingly so since about 1980, and rainfall, relatively favourable throughout the 1950s and 1960s, also experiences a downward trend (with an extreme low during the drought of 1983). On average volatility seems to be rather low, but this is only to gradually mask regional disparities as well as the high impact of changes in this marginal environment.

Figure 8: Normalized mean surface temperature in SSA, 1961-2009 (1961 = 1)



Source: Tyndall Centre for Climate Change Research

Figure 9: Normalized mean precipitation in SSA, 1961-2009 (1961 = 1)



Source: Tyndall Centre for Climate Change Research

3 MODEL SPECIFICATION

The model is based on an empirical production function pioneered by Solow (1956). The structure and explanation of the model is similar to that one of Benhabib & Spiegel (1994). Following this, the agricultural production function of Sub-Sahara African countries is modelled as:

$$Y = AL^{\beta_1}V^{\beta_2}F^{\beta_3}K^{\beta_4}M^{\beta_5}PRC^{\beta_6}TEMP^{\beta_7}e^{\varepsilon} \tag{1}$$

where *Y* represents the agricultural output, *L* labor input, *V* livestock input, *F* fertilizer input, *K* capital input and *M* land input. The connections of output to *L*, *F*, *K* and *M* are obvious, while *V* is typically used to proxy long-term internal capital formation in the agricultural sector (Hayami & Ruttan 1970, 1985; Niguyen, 1979; Mundlak & Hellinghausen 1982; Antle 1983; Frisvold & Ingram 1995; Fulginiti et al. 2004; Barrios et al. 2008). *PRC* (precipitation) and *TEMP* (temperature) are the auxiliary climatic variables of special interest in this study. Further, A is the productivity parameter, β are the coefficients, e is the error term.

After log-transformation, (1) results in:[5]

$$\begin{aligned}\log(Y_{it}) = \beta_0 + \beta_1\log(L_{it}) + \beta_2\log(V_{it}) + \beta_3\log(F_{it}) + \beta_4\log(K_{it}) + \\ \beta_5\log(M_{it}) + \beta_6\log(PRC_{it}) + \beta_7\log(TEMP_{it}) + \varepsilon_{it}\end{aligned} \tag{2}$$

with *i* (ϵ [1, N]) is denoting SSA countries and *t* (ϵ [1, T]) denoting time. Considering the fact that there are unobserved country specific and time varying effects, a two-way error component regression model is chosen for the analysis:

$$u_{it} = \mu_i + \lambda_t + v_{it} \tag{3}$$

where μ_i denotes the unobservable individual effect (purged by a within-transformation; Wallace & Hussain 1969), λ_t denotes the unobservable time effect (also intended to capture such factors as technological progress and other SSA wide influences like structural changes in agricultural systems) and v_{it} is the remainder stochastic disturbance term. Note that λ_t is individual-invariant and accounts for any time-specific effect that is not included in the

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[5] With the general form: $y_{it} = a + X'_{it}\beta + u_{it}$.

regression.[6] For analysis, a fixed-effect model is used, which allows addressing the influences of omitted variables and provides consistent estimators (Baltagi 2008). Such omitted variables may be individually colonial heritage or cultural and political differences across Sub-Saharan African countries.

The panel data used to estimate (2) is derived from three sources:

≥ The climate variables are taken form the Tyndall Centre for Climate Change Research. They provide a summary of the climate of the 20th century for 289 countries (comprised 188 countries and 101 islands and territories). The time series data set TYN CY 1.1 on the average annual rainfall and temperature from 1901 to 2009 is used for the analysis (see also Gommes & Petrassi, 1996).[7]

≥ The agricultural output data, measured in international US$ related to a base period 2004-2006, are taken from the FAO online database.[8]

≥ *L* is the total of rural population, *M* is thousands of hectares of arable land and refers to the share of land under temporary agricultural crops, temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years), both are taken from the FAO.

≥ The livestock variable *V* is measured in livestock units (total headcount of cattle, sheep and goats, the most important livestock in the Sub-Sahara African case), taken from the FAO.

≥ The technical input *F* is defined as the quantity of fertilizer in metric tons of plant nutrients (N, P205, and K20) consumed in the agricultural sector. The other technical input *K* is defined as agricultural tractors, which is also a crude proxy of capital stock. Both is taken from the FAO.[9]

Besides the climatic variables, those used in (1) are typically included in econometric analysis of agriculture (Barrios et al. 2008; Boubacar 2010; Fulginiti et al. 2004; Wiebe et al. 2000). Furthermore, the choice of inputs is constrained by the availability of comparable cross-

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[6] Additionally, it is assumed that $v_{it} \sim \mathrm{idd}(0,\sigma^2)$ and X_{it} are independent ($E[v_{it}\,Xit] = 0$) of the v_{it} for all i and t. Inference in this case is conditional on the particular N individuals and over the specific time periods observed.

[7] Until 2000 available online at: http://www.cru.uea.ac.uk/~timm/cty/obs/TYN_CY_1_1.html [17.11.2011]. Data from 2001 to 2009 was obtained directly from Ian Harris from East Anglia University, whom we consequently have to thank cordially for invaluable collaboration.

[8] This data series and the following ones from FAO are available online at: http://faostat.fao.org/ [17.11.2011].

[9] Since a lot of SSA-countries did not use fertilizers throughout the whole sample period, to allow for a balanced panel zero values are replaced by 1 in these cases. Further, data in both cases is limited to 2002 and 2003, respectively. Hence, 5-year averages were used to calculate the missing data for the missing years.

country data across Sub-Sahara Africa that covered a sufficient time span (see Frisvold & Ingram 1995 for a more differentiated, but less extensive picture). For example, there are certainly superior proxies of capital stock than the number of tractors, but not for the examined period. Additionally, measures of the level of human capital and land quality could be of particular interests. In the past some authors used school enrolment rates, literacy rates, and years of schooling as indicators of human capital. Apart from the fact that the application of these inputs would have substantially reduced the sample size, it is also important to note that these kinds of variables have generally produced very unsatisfactory results in agricultural production functions (Aboagye & Gunajl 2000).

Finally, an explanatory note to the use of a Cobb-Douglas production function to examine the effect of climatic change on agricultural production is necessary. As noted by Deschenes & Greenstone (2004), the production function approach controls explicitly for other inputs. In other words it provides estimates of the effect of weather on the yields of specific crops that are purged of bias due to determinants of agricultural output that are beyond farmers' control (like soil quality). Consequently, it is straightforward to use the results of this approach to estimate the impacts of a given change in temperature or precipitation. Its disadvantage is that the estimates do not account for profit maximizing farmers' compensatory responses to changes in climate. More specifically, a profit maximizing farmer is likely to make some adaptations in his/her manner of producing, choice of crops, usage of fertilizers, etc. Since farmer adaptations are completely constrained in the production function approach, it is likely to produce estimates of climate change that are biased downwards. However, since adaptation to climate changes was (and could be) relatively low in Sub-Sahara Africa, the bias is expected to be relatively little. Thus, the results of the regression must be viewed solely as final net impact that climate change has on agricultural output rather than measuring the full impact on the agricultural sector.[10]

Finally, for this version full data availability restricted the analysis to the four decades following widespread decolonization (1961 to 2000). While the historical dimension is crucial to understand the long-run effects of climate change (and further also the effects of structural breaks), it is clearly necessary to extend coverage as much into the present as possible, and as much into history as possible (especially to analyze political factors in more detail in the future).

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[10] An alternative is to use the Ricardian approach to measure the impact of climate change on agriculture, first pioneered by Mendelsohn et al. (1994) and later extended by Deschenes & Greenstone (2004).

4 RESULTS

4.1 *Descriptive statistics*

The variables for the available sample period 1961-2009 resulted in 2156 observations for 44 SSA countries. Basic summary statistics for all the variables are given in table 1. These show that there is considerable variation in all of the variables. Furthermore, the heterogeneity across the countries supports the assumption of the fixed effects model that each entity has its own individual characteristics that may influence agricultural production.

Table 1: Summary statistics of variables

Summary Statistics

Variable	**Mean**	**S.D.**
Y (FAO Index)	70.05	26.52
V (headcount)	9,056,443	16,456,520
F (metric tons)	35,147.04	119,336.5
K (# of tractors)	5,369.01	20,562.30
L (# of people)	6,385,409	10,101,570
M (‘000s ha)	3,179.76	5,212.33
PRC (mm)	1,057.38	629.74
TEMP (°C)	24.53	3.39
L/M	5,838.38	17,871.95
V/M	25,516.43	146,808.50
K/M	2.71	6.11
F/M	18.57	84.28

Sources: see text

In addition, summary statistics for the inputs V, K, L and F, rescaled by arable land (in ‘000 ha), reveal that other regions in the world use these factors much more intensively than countries in SSA. For instance, the means of the industrial inputs K and F per thousands of hectare of arable area are substantially higher in southern (K/M=5.68; F/M=55.85), south-eastern (K/M=3.61; F/M=72.98) and eastern Asia (K/M=17.09; F/M=188.82).[11] The livestock variable, which is an important factor for higher productivity, tends to be higher in Asian countries as well.[12] Further, univariate relationships between the climate variables and the

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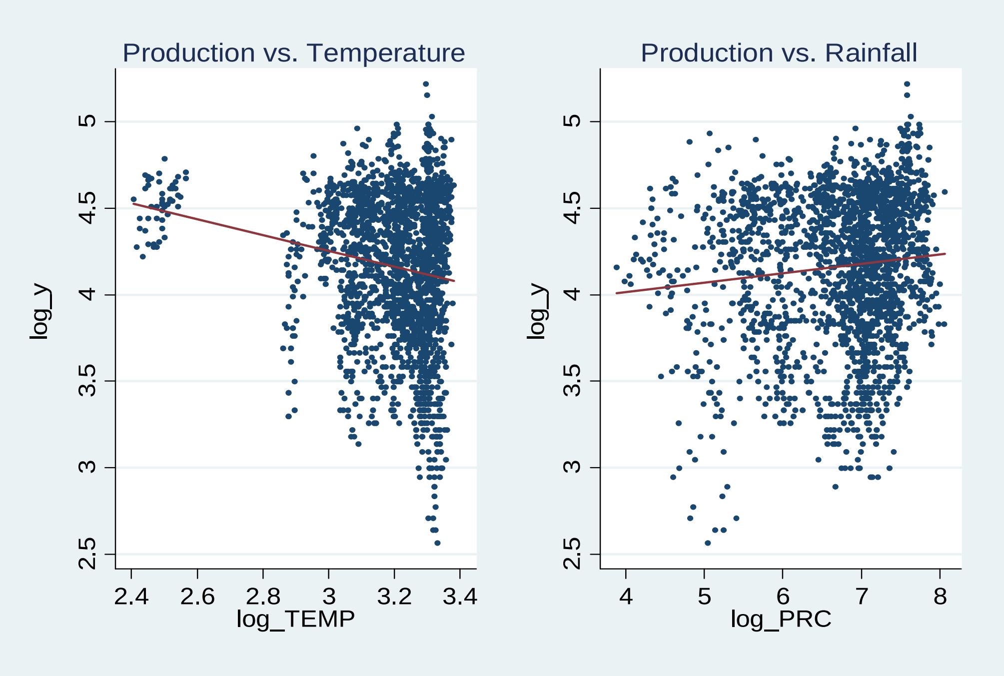
[11] Asian regions were chosen for the comparison because of the similar smallholder production systems.

[12] Data for the comparison are taken from the FAOSTAT online database.

food production index (see figure 10) show the expected trends: correlation with rainfall is positive (+0.10) while correlation with temperature is negative (-0.17).[13]

Figure 10: Univariate relationships between climate variables and agricultural production



Notes: TEMP = temperature; PRC = precipitation

Sources: see text

4.2 *Analysis*

Table 2 presents the results of the multivariate fixed-effects regression. There are two basic variants: one specification (model 1) contains all countries, the other (model 2) excludes South Africa (an outlier, as the most sophisticated agricultural sector in SSA as well as located in moderate climate). Further, there are three variants within these specifications: a benchmark model without climate variables (a), and two models with rainfall (b) and with rainfall and temperature (c), respectively. As can be seen in the benchmark models (1a and 2a), all the inputs turn out to be statistically highly significant and have the expected sign. The results also prove the traditional and small-scale structure of agriculture in SSA. Output elasticities of the traditional inputs (labor, livestock and land) are clearly higher than those of the modern inputs (capital, fertilizer).

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[13] Note that South Africa is excluded from the univariate relationships in Figure 10.

Taken together, the coefficients of labor and land are relative high compared to others. This indicates a particular structure of the agricultural sector, because small farms typically make intensive use of land by using much labor, since the costs of domestic labor are low. Considering the fact that the explanatory variable of labor is the stock of labor (persons economically active in agriculture) rather than the flow of labor services, it represents rural population density as well. This effect refers to Binswanger & Pingali (1988), who have further elaborated Boserup (1965), and consider the impacts of population pressure on land productivity: they argue that land scarcity induces institutional and technological innovations which raise land productivity and that the relative land abundance in many parts of SSA during the sample period are barriers to land productivity growth.[14]

It also seems consistent that the livestock coefficient is comparably high. New technologies require more cash investments and higher levels of education. Neither have small farms easy access to finance nor has education taken a noticeable step forward in SSA's rural population (Hazell et al. 2007). Consequently, small-farm households spend their incomes or little surplus on locally produced goods and services, which include the purchase of livestock, rather than investing in new technologies. Therefore, livestock can truly be seen as accumulation of domestic savings.

Fertilizer use has stagnated in SSA, largely because of poorly developed markets, one of the main reasons for the region's low agricultural productivity compared to Asian countries. On average, SSA farmers must sell about twice as much grain as Asian farmers to purchase a kilogram of fertilizer (WDR 2008). The progress in mechanization failed to substitute the land hoe as primary tool of land preparation and most SSA countries have experienced only little mechanization.

Model 1b and 2b introduce rainfall as explanatory variable for agricultural output. The inclusion of precipitation has little effects on the other explanatory variables. In both models, rainfall becomes a more important factor of production than the modern inputs, which again is not surprisingly for the small-scale structure in SSA. The regression coefficient of temperature has the expected sign and is significant in both models as well. This leads to the conclusion that decreases in rainfall, as much of SSA has experienced in the sample period, and constantly increasing temperatures, reduced agricultural output. However,

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[14] However, labour differs considerably among the two models. The disparity of about 0.1 in the slope coefficient can be explained by the industrialized agriculture in South Africa where the share of employment in agricultural production is general lower compared to the rest of SSA-countries.

rainfall and temperature reveal different significance levels (1% and 5%, respectively). This goes along with IPCC (1997), where it is reported that precipitation is the most important climatic element, particularly seasonal drought and the length of the growing season and especially the distribution of rainfall during the growing season affects yields. In SSA, only 4 % of the area in production is under irrigation (compared with 39 % in South Asia and 29 % in East Asia). Consequently, cropland in SSA is highly vulnerable to rainfall absence (WDR 2008), particularly its continuation (Hulme 2001), and highly depending on sufficient precipitation during the wet season.

Table 2: Agricultural production – standard specifications, model 1 (a, b, c) and 2 (a, b, c)

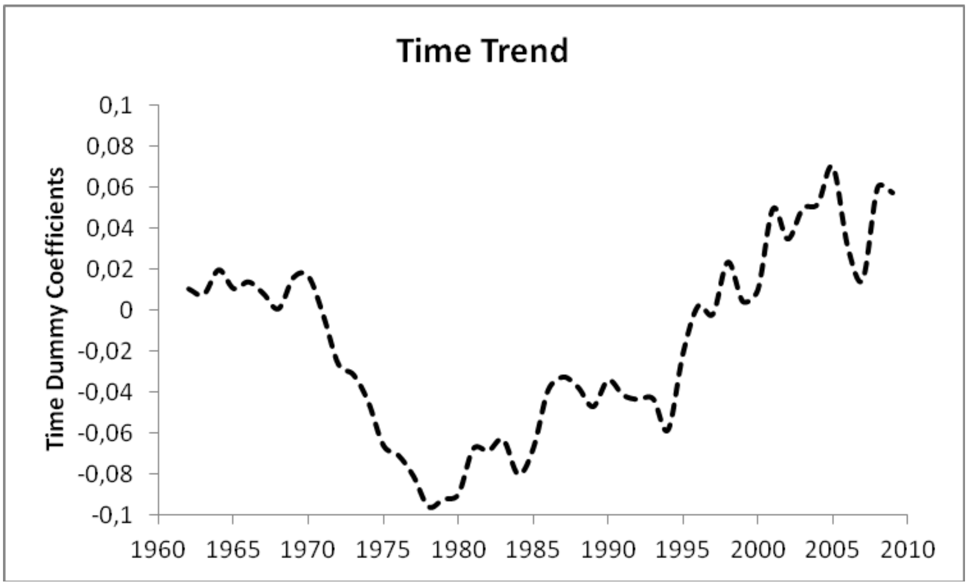
Standard specification; dependent variable: Log(Y); time period: 1961-2009

	Model 1a	Model 1b	Model 1c	Model 2a	Model 2b	Model 2c
Log(K)	0.029***	0.025***	0.025***	0.033***	0.035***	0.035***
	(0.008)	(0.008)	(0.008)	(0.009)	(0.009)	(0.009)
Log(L)	0.509***	0.501***	0.510***	0.517***	0.509***	0.520***
	(0.029)	(0.029)	(0.029)	(0.030)	(0.029)	(0.030)
Log(F)	0.015***	0.015***	0.016***	0.015***	0.015***	0.016***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Log(M)	0.107***	0.104***	0.103***	0.109***	0.106***	0.105***
	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)	(0.012)
Log(V)	0.376***	0.373***	0.371***	0.393***	0.390***	0.388***
	(0.016)	(0.016)	(0.016)	(0.017)	(0.016)	(0.016)
Log(PRC)		0.184***	0.171***		0.182***	0.167***
		(0.029)	(0.030)		(0.029)	(0.030)
Log(TEMP)			-0.719**			-0.837**
			(0.331)			(0.338)
Observations	2.156	2.156	2.156	2.107	2.107	2.107
Countries	44	44	44	43	43	43
F-test	133.50***	134.29***	132.17***	131.56***	132.23***	130.27***
F - *u*	91.51***	92.90***	91.28***	93.71***	95.08***	93.53***
Wald test	2.561***	2.034***	2.122***	2.605***	2.041***	2.170***
R^2	0.775	0.779	0.779	0.776	0.780	0.781

Notes: (1) Standard errors in parentheses. (2) ***, **, and * constitute significance at the 1%, 5% and 10% level, respectively. (3) Time dummies and intercept included in all models.

The time trend of model 2c, mainly grasping some kind of productivity development, is shown in figure 11. The results, particularly the decline during the 1970s, are in accordance with authors that investigated technical change in Sub-Sahara Africa (Busari et al. 2005; Fulingiti et al. 2004; Nkamleu 2007). The boost of the time trend from 1984/85 reflects the implemented structural adjustment policies in SSA countries. During this time the focus lay on stabilization, growth and liberalization in African agriculture. As short term measures price incentives for the production of food, raw materials and export commodities were restored. In the growth phase, increased productivity and internal price stability were emphasized. Especially, improved planting materials and fertilizer availability had immediate impacts on food crop production. In the final phase, reforms guaranteed a minimum price for food commodities and subsidies for agricultural inputs were removed (Seini & Nyanteng 2006).

Figure 11: Time trend according to model 2c (time dummy coefficients)



4.3 Some further observations

To investigate technology further, two country groups are formed: group 1 (model 3a, “med-tech countries”) consists of countries with relative large amounts of tractors during the sample period; group 2 (model 3b, “low-tech countries”) represents countries with low agricultural mechanization.

Results show that the relevant elasticity is high and significant in group 1, but low and insignificant in group 2. Also the traditional input labour – as well as livestock – is clearly smaller in group 1 compared to group 2, which indicates that mechanization generally substituted labour. Particularly, mechanization can overcome seasonal shortages of labour and/or releases labour in critical periods for other productive tasks. Consequently, the contribution of agriculture to the GDP is lower in these countries: about 25 % in group 1 and

40 % in group 2 (WDI 2009). The case of livestock is similar to that of labour, while interestingly the impact of fertilizers becomes negative in group 1.

Table 3: Agricultural production and mechanization

Agricultural mechanization; dependent variable: Log(Y); time period: 1961-2009; model 3a refers to group 1, model 3b to group 2

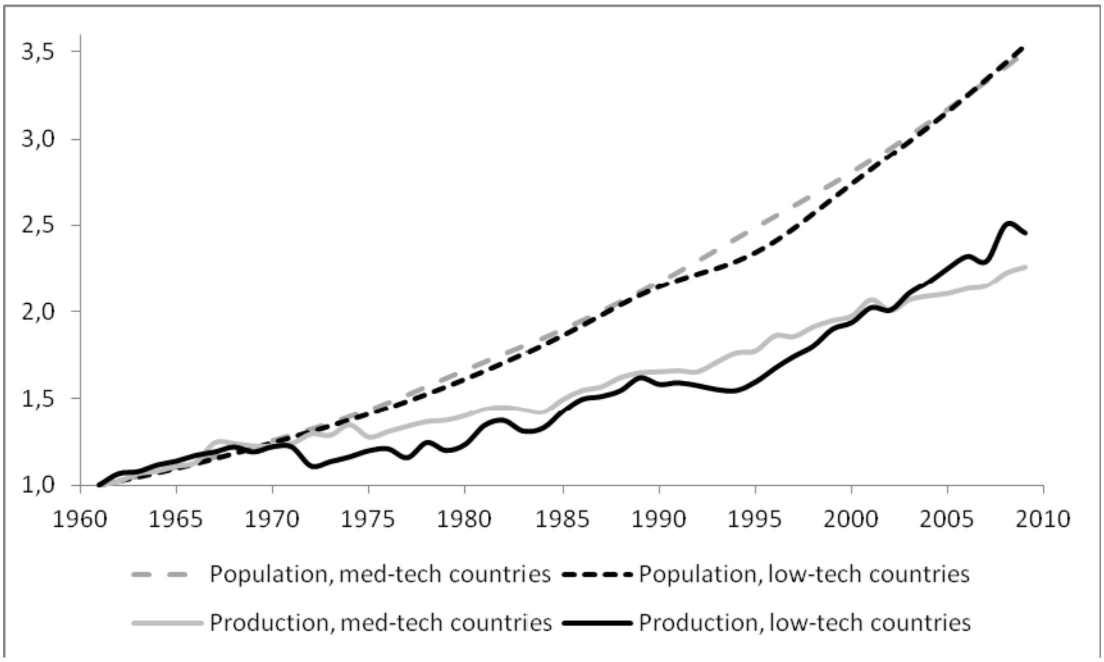
	Model 3a	Model 3b
Log(K)	0.137^{***}	-0.021
	(0.020)	(0.015)
Log(L)	0.829^{***}	1.092^{***}
	(0.065)	(0.073)
Log(F)	-0.016^{**}	0.018^{***}
	(0.007)	(0.004)
Log(M)	0.325^{***}	0.051^{***}
	(0.049)	(0.015)
Log(V)	0.191^{***}	0.418^{***}
	(0.034)	(0.055)
Observations	539	735
Countries	11	15
F-test	57.24^{***}	41.06^{***}
F - *u*	76.45^{***}	72.61^{***}
Wald test	2.278^{***}	1.181
R^2	0.865	0.765

Notes: (1) Standard errors in parentheses. (2) ***, **, and * constitute 1%, 5% and 10% significance levels, respectively. (3) Time dummies included in all models.

When looking at the summarizing figure 12, revealing a somewhat Malthusian picture of SSA agriculture, one has also to note that mechanization had ambiguous effects on economies at the national level (Belete et al. 1991; Mrema et al. 2008; Taylor 1992; van Zyl et al. 1987). While in the last decade the effect of mechanization in low-tech countries was on average more favorable than in med-tech countries (probably due to a catch-up-effect), earlier and in unsuitable situations, the application of tractors and heavy mechanization also led to a higher investment burden and environmental degradation, which resulted in lower agricultural production and sometimes even productivity.

One of the standard specifications' problems is data restriction to the country level. Hence we now allow for the diversity of geographic size in SSA countries as a first step to consider this problem, since the standard model is much more convenient for smaller, climatically more homogeneous countries. To investigate this, the log function of each country size was interacted with the rainfall variable (model 4). The resulting coefficient is negative and statistically significant, which is in line with a priori expectations (smaller countries are more severely affected by rainfall deficits, since they are less able to balance these within the country).[15]

Figure 12: Agricultural production, mechanization and population growth (1961 = 1)



Source: FAOSTAT

The standard specification also assumes that the climatic effects are similar across Africa, which is not necessarily likely. Based on the classification of regional agriculture in the IPCC report (2001) and in order to investigate the impact that intra-continental differences in climate might have on agricultural production, SSA is divided into its six common regional groups (model 5a): Sudan-Sahel, Gulf of Guinea, Central Africa, Eastern Africa, Southern Africa and Indian Ocean Island. For each group simple zero-one type dummies were created and interacted with the log functions of the temperature and rainfall variables. A second approach (model 5b) was to divide SSA countries into four rainfall groups (< 500 mm, < 1,100 mm, < 1,500 mm, and > 1,500 mm, respectively). For details on group membership see table 5 in the appendix.

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[15] This exercise was exclusively done with the rainfall variable because the spatial variability of temperature is much smaller and its impact hardly measurable (Hulme et al. 2005)

Table 4: Agricultural production and climate change on a regional basis

Alternative specifications; dependent variable: Log(Y); time period: 1961-2009				
	Model 4	Model 5a	Model 5b	Model 5c
Log(L)	0.518***	0.501***	0.521***	0.513***
	(0.030)	(0.029)	(0.030)	(0.029)
Log(F)	0.016***	0.016***	0.015***	0.016***
	(0.002)	(0.002)	(0.002)	(0.002)
Log(M)	0.104***	0.103***	0.096***	0.107***
	(0.012)	(0.012)	(0.012)	(0.012)
Log(V)	0.390***	0.393***	0.387***	0.391***
	(0.016)	(0.016)	(0.017)	(0.016)
Log(PRC))	0.469***			
	(0.132)			
Log(TEMP)	-0.905***			
	(0.339)			
Log(PRC)*Log(GEO-SIZE)	-0.032**			
	(0.014)			
Log(PRC)*Sudan_Sahel		0.318***	0.317***	
		(0.049)	(0.049)	
Log(PRC)*Southern		0.076	0.029	
		(0.047)	(0.050)	
Log(PRC)*Gulf		0.122	0.171***	
		(0.081)	(0.080)	
Log(PRC)*Central		0.542***	0.551***	
		(0.126)	(0.124)	
Log(PRC)*Ocean		0.165*	0.168*	
		(0.091)	(0.090)	
Log(PRC)*Eastern		0.038	0.001	
		(0.104)	(0.103)	
Log(TEMP)*Sudan_Sahel			-0.018	
			(0.523)	
Log(TEMP)*Southern			-1.221***	
			(0.427)	
Log(TEMP)*Gulf			2.564***	
			(0.712)	
Log(TEMP)*Central			-3.158***	
			(0.790)	
Log(TEMP)*Ocean			0.114	
			(1.006)	
Log(TEMP)*Eastern			-2.232***	
			(0.565)	
Log(PRC)*group1 (= rain < 500 mm)				0.115**
				(0.046)
Log(PRC)*group2 (= rain < 1,100 mm)				0.269***
				(0.048)
Log(PRC)*group3 (= rain < 1,500 mm)				0.226***
				(0.076)
Log(PRC)*group4 (= rain > 1,500 mm)				0.118*
				(0.067)
Observations	2107	2107	2107	2107
Countries	43	43	43	43
F-test	128.32***	122.59***	115.58***	125.65***
F - *u*	93.87***	94.75***	93.89***	93.83***
Wald test	2.259***	1.839***	2.009***	2.009***
R^2	0.782	0.783	0.790	0.781

Notes: (1) Standard errors in parentheses. (2) ***, **, and * constitute 1%, 5% and 10% significance levels, respectively. (3) Time dummies and intercept included in all models.

Model 5a shows that the interaction terms result in considerable heterogeneity in the country level response to rainfall. More precisely, the highest and most significant impact is found in the Central region, followed by the Sudan-Sahel region. A small, moderately significant effect is found in the Indian Ocean region as well. In contrast, no significant effect is found for the Eastern, Gulf of Guinea and Southern regions. Including an interaction term with the temperature variable in Model 5b does not essentially alter these findings concerning regional impact of rainfall, though the effect for the Gulf of Guinea region now becomes significant. In terms of temperature the highest significant negative impacts are found in Central, Eastern Africa and in the Southern regions. Particularly with respect to the Sudan-Sahel region and Gulf of Guinea (where increasing temperature turns out to have positive effects on production), these results are fully in line with previous findings. However, the lack of significant impact does not mean that climate has not affected agricultural production in the other regions. It may just be that the country level aggregation or the geographic classification is too simplistic to describe the underlying climatic patterns.

Concerning the rainfall groups, the effect is gradually non-linear. In rain-abundant environments, the interaction term of rainfall is small and significant on the 5% level, while the highest impact of rainfall on agricultural production is found in countries with mean rainfall from 500 to 1,100 mm per year. Furthermore, these country-groups are dominated by two major farming systems: the Cereal-Root Crop Mixed and Maize Mixed Farming System. The latter one is the most important food production system in East and Southern Africa. Both systems are predominantly located in the dry sub-humid zone. Additionally, the maize belt and the other countries of the group had the highest recurring drought events since the 1970s. Since both systems account for 23 % of the total land area in SSA and their yields per hectare are one of the highest in the region, it seems consistent that rainfall absence has evident impact on production. The low effect in countries with less than 500 mm rainfall is very likely also closely correlated to production patterns, since these countries are located in the semi-arid and arid zones, in which pastoralism dominates and cultivated land is generally sparse, both resulting in low production levels (Dixon et al. 2001).

5 CONCLUSION

In this paper we have shown that climate change influenced agricultural production in Sub-Saharan Africa in an unfavourable way. When considering traditional and modern inputs (labour, land and livestock, as well as capital and fertilizer, respectively) in a fixed-effects-model, particularly the effect of rainfall is significantly positive and important. This is also in line with expectations that the effect of temperature, which is significantly negative in some specifications, will be less relevant and lower. Further, by separating countries into a low- and a med-tech group (with respect to modern inputs), different relationships between the standard factors could be revealed, and by refining the specification with respect to regional, climatic differences some complexities in these general patterns could be shown. Especially these extensions already show that a more differentiated picture has to be drawn to come to more detailed conclusions, notwithstanding data availability restrictions on the sub-national level. Overall, these findings are not encouraging given the actual trends in rainfall and temperature in Sub-Sahara Africa, both having a negative impact on agricultural production.

Clearly, the model needs further refinement (some problems are discussed in the appendix) before extending it to some other relevant issues like policy variables (which are likely to explain the negative time trend during the 1970s and mid-2000s) and in time (which is also necessary to better grasp the effect of technological change). However, we have already shown that the exercise is worth while, particularly given the importance of food security in Africa and the necessity to appropriate adaption strategies to stabilize and sustain agricultural production in times of climate change. This holds even more, since African resource endowments call for an intensification of agricultural production, as long as well-adapted to local environments – be it natural, political or economic ones.

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Appendix:

Country groupings

Table 5a: Mechanization (model 3):

Group 1 – mechanized countries	Group 2 – low mechanized countries
Angola	Benin
Botswana	Burundi
Ivory Coast	Cameroon
Ghana	Chad
Guinea	Djibouti
Kenya	Equatorial Guinea
Mozambique	Gambia
Nigeria	Guinea Bissau
Swaziland	Liberia
Zambia	Mauritania
Zimbabwe	Niger
	Rwanda
	Senegal
	Sierra Leone
	Togo

Table 5b: Geographic groups (model 4 and 5)

Sudan-Sahel	Gulf of Guinea	Central Africa	Eastern Africa	Southern Africa	Indian Ocean Islands
Burkina Faso	Benin	Angola	Burundi	Botswana	Comoros
Cape Verde	Ivory Coast	Central Africa	Kenya	Lesotho	Madagascar
Djibouti	Ghana	Cameroon	Rwanda	Mozambique	Mauritius
Gambia	Guinea	Congo	Uganda	Malawi	Sychelles
Mali	Guinea Bissau	Gabon		Namibia	
Mauritania	Liberia	Equatorial Guinea		Swaziland	
Niger	Nigeria	Zaire		South Africa	
Sudan	Sierra Leone			Zambia	
Senegal	Togo			Zimbabwe	
Somalia					
Chad					

Table 5c: Rainfall groups, based on mean rainfall, 1950-2000 (model 5)

Rain < 500 mm	Rain < 1.100 mm	Rain <1.500 mm	Rain > 1.500 mm
Mauritania	Kenya	Uganda	Zaire
Niger	Zimbabwe	Malawi	Congo
Somalia	Senegal	Nigeria	Cameroon
Namibia	Burkina Faso	Rwanda	Guinea Bissau
Mali	Swaziland	Togo	Guinea
Chad	Gambia	Burundi	Comoros
Lesotho	Zambia	Ghana	Gabon
Botswana	Angola	Djibouti	Sychelles
Cape Verde	Mozambique	Central Africa	Mauritius
Sudan	Benin	Ivory Coast	Euatorial Guinea
		Madagascar	Liberia
			Sierra Leone

Testing for Autocorrelation and Unit Root in the dataset

First-order autocorrelation in the variables and regression with AR(1) disturbance

Table 6: Calculation of Autocorrelations at lag 1

First-order autocorrelation coefficients

	Log(Y)	L1.log(Y)
log(Y)	1	
L1.log(Y)	**0.98**	1
	log(K)	L1.log(K)
log(K)	1	
L1.log(K)	**0.99**	1
	log(F)	L1.log(F)
log(F)	1	
L1.log(F)	0.95	1
	log(V)	L1.log(V)
log(V)	1	
L1.log(V)	**0.99**	1
	log(M)	L1.log(M)
log(M)	1	
L1.log(M)	**0.99**	1
	log(L)	L1.log(L)
log(L)	1	
L1.log(L)	**1**	1
	log(PRC)	L1.log(PRC)
log(PRC)	1	
L1.log(PRC)	**0.32**	1
	log(TEMP)	L1.log(TEMP)
log(TEMP)	1	
L1.log(TEMP)	**0.71**	1

As indicated in Table 6, the output and input variables are highly autocorrelated, while, as expected, the climate variables are moderately correlated at lag 1. The calculations assume that the errors in the standard specification are serially correlated as well. This leads to a misspecification of the model since the standard errors are biased. In other words the test statistics are invalid in presence of serial correlation.

For this reason, a two-way fixed effects model with an AR(1) disturbance is estimated. Table 7 shows the results when the disturbance term is first-order autoregressive. At the end of the table, the Baltagi-Wu locally best invariant (LBI) test statistic and a modified version of the Bhargava et al. Durbin-Watson statistic are calculated and reported. In both cases the null hypothesis of no serial correlation is clearly rejected.

Table 7: Two-way fixed effects with an AR(1) disturbance

AR(1) disturbance	Model AR(1)
Log(K)	-0.001 (0.019)
Log(L)	0.427*** (0.100)
Log(F)	0.005*** (0.002)
Log(M)	0.018*** (0.007)
Log(V)	0.239*** (0.030)
Log(PRC)	0.097*** (0.012)
Log(TEMP)	-0.414** (0.169)
Observations	2.064
Countries	43
F-test	11.43***
F - *u*	4.17***
Wald test	1.620***
R^2	0.234
Modified Bhargava, Durbin-Watson	0.302
Baltagi-Wu LBI	0.375

Notes: (1) Standard errors in parentheses. (2) ***, **, and * constitute significance at the 1%, 5% and 10% level, respectively. (3) Time dummies and intercept included in all models.

Testing for Unit Root in the Standard Specification

Since the standard specification of the panel data set contains large N and T, one might believe that there is a possibility of a unit root even in the individual country series. For instance, the introduction of SAPs or oil price shocks may trigger such random walks. In order to test stationarity, the unit root test for heterogeneous panels developed by Kyung et al. (2003) was implemented. The test is based on the mean of individual unit root statistics and uses a standardized t-bar test statistic base on the augmented Dickey-Fuller statistics averaged across countries.

Table 8 indicates that the existence of a unit root in the used variables cannot be fully eliminated. By using different lag-lengths or including a trend in the test, all variables, expect for the livestock, reject the null hypothesis of a unit root. These findings reflect the problems in macroeconomic approaches with large T. Regarding to unit root problems in the specification, future research activities need to refine the model. One way is to apply methods for non-stationary time series panels, for instance panel cointegration.

Table 8: Im-Pesaran-Shin panel unit root test

Unit root test results for N, T = (44,49);

variable	t-bar	cv10	cv5	p-value	lag-length	trend	stationarity
Log(Y)	-1.525	-1.680	-1.730	0.506	0	No	No
	-1.204	-1.680	-1.730	0.992	1	No	No
	-2.587	-2.320	-2.360	0.000	0	Yes	Yes
Log(K)	-5.206	-1.680	-1.730	0.000	0	No	Yes
	-2.846	-1.680	-1.730	0.000	1	No	Yes
	-2.648	-1.680	-1.730	0.000	4	No	Yes
	-4.859	-2.320	-2.360	0.000	0	Yes	Yes
	-3.067	-2.320	-2.360	0.000	3	Yes	Yes
Log(F)	-2.609	-1.680	-1.730	0.000	0	No	Yes
	-2.381	-1.680	-1.730	0.000	1	No	Yes
	-3.165	-2.320	-2.360	0.000	0	Yes	Yes
	-2.814	-2.320	-2.360	0.002	2	Yes	Yes
Log(V)	-1.058	-1.690	-1.730	1.000	0	No	No
	-1.306	-1.680	-1.730	0.949	1	No	No
	-1.674	-2.320	-2.360	1.000	0	Yes	No
	-2.028	-2.320	-2.360	0.894	1	Yes	No
Log(L)	0.730	-1.680	-1.730	1.000	0	No	No
	-2.316	-1.680	-1.730	0.000	1	No	Yes
	-1.190	-1.670	-1.730	0.969	5	No	No
	0.211	-2.320	-2.360	1.000	0	Yes	No
	-4.069	-2.320	-2.360	0.000	1	Yes	Yes
Log(M)	-1.670	-1.680	-1.730	0.138	0	No	No
	-1.727	-1.680	-1.730	0.063	1	No	Yes
	-2.973	-2.320	-2.360	0.000	0	Yes	Yes
	-3.454	-2.320	-2.360	0.000	1	Yes	No
Log(PRC)	-6.433	-2.320	-2.360	0.000	0	No	Yes
	-4.484	-2.320	-2.360	0.000	1	No	Yes
	-2.720	-2.320	-2.360	0.000	4	Yes	Yes
Log(TEMP)	-4.389	-1.680	-1.730	0.000	0	No	Yes
	-3.232	-1.680	-1.730	0.000	1	No	Yes
	-5.118	-2.320	-2.360	0.000	0	Yes	Yes
	-2.898	-2.320	-2.360	0.000	3	Yes	Yes

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Rain, temperature and agricultural production: The impact of climate change in Sub-Sahara Africa, 1961-2009

Abstract

This paper is about the effect of climate change on Sub-Sahara African (SSA) agricultural production in a post-colonial setting. While agricultural production certainly is the result of a multi-dimensional process (influenced by diverse branches of politics, by technology, and also by trade patters and violent conflicts, among others), already the partial analysis of the most obvious factors of influence is certainly valuable in the African case. Since agriculture is not only the single most important sector for the greatest majority of people there, but also a low-tech endeavor in Africa, the impact of temperature and particularly rainfall is crucial – to the point of life-threatening crop failure. In sum, we are able to shown that climate change influenced agricultural production in Sub-Sahara Africa in an unfavourable way. When considering traditional and modern inputs (labour, land and livestock, as well as capital and fertilizer, respectively) in a fixed-effects-model, particularly the effect of rainfall is significantly positive and important. Further, by separating countries into a low- and a med-tech group (with respect to modern inputs), different relationships between the standard factors can be revealed, and by refining the specification with respect to regional climatic differences some complexities in these general patterns can be shown.

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