Global climate change and vulnerability of African agriculture: implications for resilience and sustained productive capacity

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Abstract

Despite noticeable improvements in recent socio-economic performance in Africa, variations exist across countries and performance is constrained by plethora of factors that inhibit the attainment of Africa's optimum production potential. Changing climate and environmental factors have contributed to increased transactions costs, lower productivity of factors of production, increased bottlenecks in the production process and investment challenges, especially for small and medium scale farmers in varying degrees across the continent. This paper reviews the impact of climate change on farming activities in Africa. Four countries across the continent are studied, viz. Burkina Faso, Egypt, Kenya and South Africa. We examine how long-term profitability of 4,000 farms vary with local climate, such as temperature and precipitation. To better ascertain the impact of climate variables, the marginal impacts of unit changes in temperatures and precipitation on crop farming activities are studied. Using selected climate scenarios, predictions are made on the extent to which projected climate changes will affect net revenues by the year 2050 and 2100. The findings suggest that climate affects agricultural returns in the four countries. The results further show that there is a non-linear relationship between temperature and crop revenue on the one hand and between precipitation and crop revenue on the other. Overall, the temperature elasticity suggests that global warming is harmful for agriculture across all the countries. These have profound implications for the policy requirements to address the productive capacity and resilience of the agricultural sector. Effort will be required to enhance adaptation at farm, regional and national levels. Policy adjustments will in addition require increased liberalization of the financial system and an implementation of agriculture civil service reforms for better performance of the extension service. This may have further implications for state budgeting and agriculture sector expenditures which will without doubt require new shifts.

Keywords: Africa, climate change, agriculture, vulnerability, resilience, productive capacity
JEL: C32, D81, Q11

1. Introduction

Current climatic variation has significant impacts on agricultural production, constraining agricultural income and forcing farmers to adopt new agricultural practices in response to altered conditions. The risks of future climatic changes such as higher temperatures, changes in precipitation and increased climate variability can result in significant impacts on agriculture and rural areas, and attendant macroeconomic consequences for nation states (ROSENZWEIG and PARRY, 1993; MENDELSOHN and WILLIAMS, 2004; KURUKULASURIYA et al., 2006; IPCC, 2007). For countries with significant proportion of agrarian economies climate change is expected to have significant microeconomic and macro-consequences (MENDELSOHN and DINAR, 2003; DERESA et al., 2005; GBETIBOUO and HASSAN, 2005).

Africa is one of the world's largest continents, covering over 35 million km^2 and including about 48 countries. Sub-Saharan Africa counts a total land area of 2,455 million ha, of which 173 million ha (about one quarter of the potentially arable area) are under annual cultivation or permanent crops (FAO, 2002). African economies depend on semi-subsistence agriculture. Agriculture accounts for 20% of the continent's GDP (WORLD BANK, 2000a), employs 67% of the total labour force and is the main source of livelihood (DIXON et al., 2001). Over 90% of farms are small, farming less than 5 ha, with about two-thirds having less than 1.5 ha (SPENCER, 2001). These small-scale farms account for over 80% of agricultural production and support the food and fibre needs of about 600 million people in the continent. The continent's environment is closely linked with its climate such that climatic constraints are a major force in the development of vegetation, soils, agriculture, economic development and general livelihood.

Actual revenue increases for the agricultural sector in most African countries as a result of increases in global commodity prices and opening up of some export markets has masked the stagnating per capita production. Per capita agricultural production has stagnated primarily due to unfavorable weather for the rainfed crop production. Some important questions that this paper seeks to answer include: how vulnerable is African agriculture to a changed climate? What are the consequences on current and future macroeconomic policy? Primarily, the goal of this paper is to review and put in perspective the extent to which the productive capacity of selected countries: Burkina Faso, Egypt, Kenya and South Africa are vulnerable to climate change.

2. Mounting evidence of global warming and climate change

The IPCC reports in its Fourth Assessment Report that the earth's climate is changing, and the rate of change is accelerating with man's economic activity having a discernible effect on the climate. The best judgement of the Intergovernmental Panel on Climate Change (IPCC, 2007) is that if emissions of greenhouse gases (GHG) continue to grow as currently projected the global mean temperature will increase over the current century. These changes in greenhouse gases may not only lead to changes in temperature, precipitation and other climate variables, but may also result to global changes in soil moisture and increase in global mean sea level, and prospects for more severe extreme temperature events, flood and droughts in some places.

Crop plants have an inherent relationship with climate and the environment. Global environmental changes in atmospheric carbon dioxide, land transformation and anthropogenic nitrogen fixation, affect plant photosynthesis, respiration and decomposition, thus leading to changes in plant carbon dioxide fixation and the carbon stocks in vegetation and soils (MELILLO et al., 1993; SCHIMEL et al., 1994; VITOUSEK et al., 1997). Thus, the risks of changing weather conditions in relation to higher temperatures, changes in precipitation, increased climate variability and extreme weather events can result in strong significant impacts on agriculture, forestry and rural areas (ADAMS et al., 1990; MENDELSOHN et al., 1994; EASTERLING et al., 1993; LANG, 2001).

As a consequence of its vast size and opportunity and that Africa sits astride the equator, this results in a more or less symmetrical distribution of climate about the equator (THOMPSON, 1965), which is modified by regional factors such as topography and large water bodies. In other words, Africa experiences a wide variety of climate regimes, ranging from deserts to tropical rainforests (see KRISHNAMURTI and OGALLO, 1989). As a result of its latitudinal span (27^o N to 34.5^o S), there is a zonal distribution of climate from the meteorological equator northwards and southwards (OLAGO, 2001). The equatorial zone experiences the confluence of airflow from the northern to southern hemispheres, and the confluence zone migrates northward to about 15^o to 24^o N in June to August, and southward to about 8^o N to 16^o S in December to February giving rise to humid climate with a double rainfall maximum, flanked on the north and south by broad belts of monsoon climates characterised by summer rains and winter drought (STREET-PERROTT and PERROTT, 1993). The monsoon climate belts are flanked to the north by the arid Sahara and to the south by semi-arid and savanna regions. The temperate northern and southern extremities of the continent, which project into the belts of the mid-latitude westerlies, experience westerly cyclonic disturbances which give rise to high winter precipitation (STREET-PERROTT and PERROTT, 1993). Across the Kalahari and Sahara desert regions, precipitation is inhibited by sinking motion virtually throughout the year. In contrast to the equatorial and tropical regions which are characterised by abundant precipitation concentrated along the Inter-Tropical Convergence Zone (ITCZ) (SEMAZZI and SONG, 2001). Since the movement of the ITCZ trails the position of maximum surface heating associated with the north/south displacement of the overhead position of the sun, the equatorial region have two rainy seasons while most of the other regions of the continent have only one distinct rainy period during the year (*ibid*.).

Despite the relative dearth of quantitative records prior to 1900, adequate historical information has been put together to produce reliable picture of climate variability throughout the 19^{th} century (HASTENRATH, 2001; NICHOLSON, 1978) using proxy material dealing with such phenomena as drought, goods and harvests, and various hydrological indicators. According to NICHOLSON (2001) and HASTENRATH (2001) climate and environmental conditions that prevailed over Africa long ago were quite unlike those of today. Table 1 presents the magnitude of the rainfall anomalies for the 1970s and 1980s in Africa. In the arid region of West Africa, rainfall was about half a standard deviation (SD) below the long-term mean of the 1970s, but approximately 0.8 SDs in the 1980s. The change in the more humid Guinean regions was more moderate but was also greater in the 1980s. In east Africa the averages for the two decades were 0.04 and 0.15 SD above normal, respectively. In southern Africa, the increase in the 1970s, up to 0.56 SDs, was almost equivalent to the decrease in the rainfall in the 1980s. In summary, rainfall was below normal throughout most of Africa during the 1980s, and this pattern generally prevailed in the 1990s (NICHOLSON, 2001). NICHOLSON (2001) further indicates that dry conditions were frequent during the 1840s, 1850s and early 1860s in all four regions (Sahel, Eastern Africa, Southern Africa-N and Southern Africa-S), analogous to the 1980 decade. This was a continuation of the drier conditions that occurred during the first few decades of the century (1900-1920). In the 1960s, however, rainfall increased over much of the equatorial region, associated with increase in the level of the Rift Valley lakes (see NICHOLSON and YIN, 2000). By the early 1970s, increased aridity was wide spread, with southern Africa observing relatively wet regimes. By the 1980s, rainfall was below the long-term mean over most of Africa. This trend continued into the 1990s. In the last 3 to 4 decades (1960-2000), rainfall was predominantly above average on all the regions but East Africa, a pattern quite similar to the 1950s.

Table 1. Magnitude of rainfall anomalies in Africa for the period 1970-1979 and 1980-1989

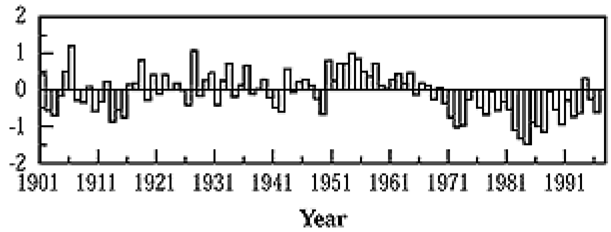
Sub-Region	1979-79		1980-89	
	%	% σ	%	% σ
Sahelo-Sahara	-31	-47	-24	-35
Sahel	-22	-55	-31	-82
Sudan Savanna	-13	-53	-20	-85
Sudano-Guinean Zone	-5	-36	-8	-56
Guinea Coast	-6	-31	-7	-35
Eastern Africa	0	4	2	15
South Africa-North	6	20	-5	-21
South Africa-South	10	34	-7	-27
South Africa-West	26	56	-12	-25

Note: Regionally averaged rainfall is expressed as a percent departure from the long-term mean and as a standardised departure [ratio of the departure from the mean to the standard deviation (SD)].
Source: NICHOLSON (2001)

According to NICHOLSON (2001) one of the most significant climatic variations has been the persistent decline in rainfall in the Sahel since the late 1960s. Mean rainfall decreased by 20-40% in the Sahel between the periods 1931-1960 and 1968-1997 and generally 5-10% across the rest of the continent (see figure 1). The trend was abruptly interrupted by a return of adequate rainfall conditions in 1994. This was considered to be the wettest of the past 30 years and was thought to perhaps indicate the end of the drought. However, dry conditions returned after 1994 (IPCC, 2001). Linear regression of 1901-1990 rainfall data from 24 stations in the west African Sahel yields a negative slope amounting to a fall of 1.9 standard deviations in the period 1950-1985 (NICHOLSON and PALAO, 1993). For the years ahead, HEWITSON (1997) simulates precipitation to increase over much of the African continent by the year 2050. Similarly, HERNES et al. (1995) constructed climate change scenarios for the African continent that showed land areas over the Sahara and semi-arid parts of southern Africa warming by 2050s by as much as 1.6 ^{o}C and the equatorial African countries warming at a slightly slower rate of about 1.4 ^{o}C.

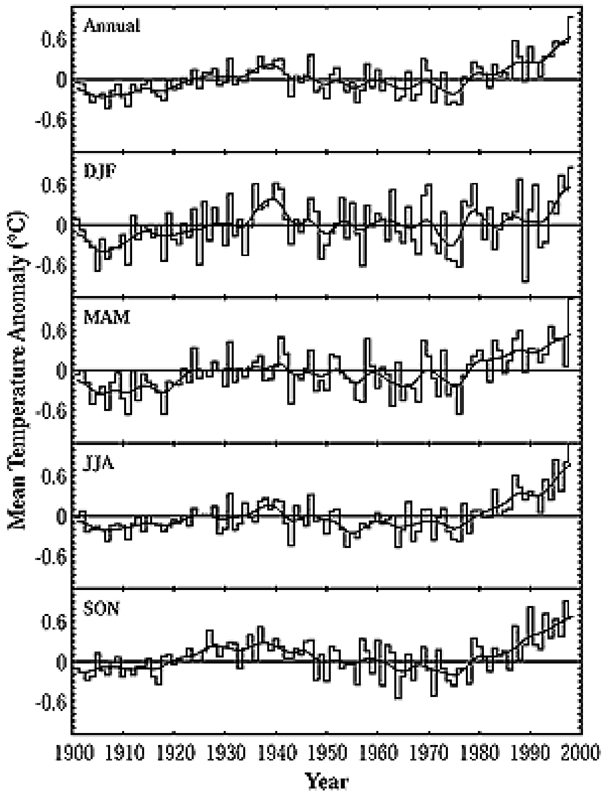
In effect, records show that the continent of Africa is warmer than it was 100 years ago (HULME et al., 2001) and warming through the 20th century has been at the rate of about 0.05 °C per decade, with slightly larger warming in the June, July, August (JJA) and September-November seasons than in December, January, February (DJF) and March-May (HULME et al., 2001). The five warmest years in Africa have all occurred since 1988, with 1988 and 1995 the two warmest years (figure 2). This rate of warming is not dissimilar to that experienced globally. Comparing data, the periods of most rapid warming (the 1910s to 1930s and the post-1970s) occur simultaneously in Africa and the world. The climate of Africa has experienced wetter and drier intervals during the past 2 centuries. The most pronounced periods were during the 20th century.

Figure 1. Rainfall fluctuations, 1901-1998, expressed as regionally averaged standard deviation (departure from long-term mean divided by standard deviation) for the Sahel



Source: IPCC (2001)

Figure 2. Annual temperatures in Africa[1]



Source: HULME et al. (2001)

1 Mean surface air temperature anomalies for the African continent, 1901-1998, expressed with respect to 1961-1990 average, annual and four seasons (DJF, MAM, JJA, SON).

Africa is very vulnerable to short-term climatic variability principally because it has a weak financial base with which to cope with these changes (WORLD BANK, 1998). Climate variability could have high cost for poor families in terms of savings and capital accumulation and often increases income and wealth disparities. African agriculture, of which 85-90% is rain-fed, year-to-year swings in GDP can be as high as 15-20% largely as a result of fluctuations in rainfall (see BENSON and CLAY, 1998). The impact of climate change on agricultural production will vary according to sub-region, but the Intergovernmental Panel on Climate Change (IPCC, 2007) projects significant reduction in output, for a continent where food insecurity and hunger are already prevalent. The unpleasant effects of climate change may further be fuelled by factors such as population pressure,[2] land degradation, low level of capital investment and policy conditions that reduce the provision of farmer support services. In effect, therefore, the continent is potentially vulnerable to various ramifications of climate change. This raises some pertinent questions. What will be the impact on the quality of life in the continent? Will climate change help or hinder efforts to maintain adequate food supply for the increasing population? Which sub-regions are likely to benefit and which are likely to suffer food shortages and socio-economic crises?

3. African agriculture outlook and production trends

Despite the abundant human and natural resources, productivity gains and income accruing to agriculture have been associated with a downward trend. The average Gross Domestic Product (GDP) per capita in constant prices was lower at the end of the 1990s than in 1970 (WORLD BANK, 2000b). Nineteen of the 25 poorest countries in the world are found in the region and income inequality is high (WORLD BANK, 2000c). The share of agricultural GDP is declining in more than one third of countries in the region, and in a further one quarter it is increasing[3]. One will expect that a declining share of agricultural GDP is the result of rapid growth in non-agricultural sectors, and increases in the contribution of agriculture to national GDP stem from growth of agricultural value added. However, this has not been the case for the region. The declining shares of agriculture has been due to poor performance of the sector, and for countries with increasing sectoral GDP this is attributed to declines in non-

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[2] Africa's population growth, along with Asia's, is the fastest in the world, growing at about 3% per year and projected at 1.4 billion by 2025 (UNITED NATIONS, 2001). The rapid human population growth is creating severe impacts on natural resources. Land is degraded by the overgrazing of livestock and deforestation accelerated by fuelwood collectors and 'slash-and-burn' field crop cultivators.

[3] The sharpest declines were reported in Eritrea, Angola, Uganda, Ghana, Ivory Coast, Mozambique, Mauritania and Lesotho and the greatest increases in the Congo Republic, Cameroon, Rwanda, Togo, Niger, Benin, Namibia, Central African Republic, Zimbabwe and Mali.

agricultural sector output (see Dixon *et al*., 2001). Some factors occurring individually or in multiplicity or in coincidence, or as a result of chain reactions, constitute major challenges for profitable farming in sub-Saharan Africa (MOLUA and RAJAB, 2002). What, therefore, are the challenges for profitable agriculture in Africa? The Economic Commission for Africa of the United Nations (ECA, 1989) and YAKER (1993) identify hostile climatic conditions punctuated with periodic calamities (e.g. floods and drought) as one of major challenges facing producers in the continent. Other important constraints to production include inappropriate policies and poor planning, political conflicts and civil wars, deforestation and degradation of the natural resource base, obsolete and inadequate production technology, and the dearth of production and marketing infrastructures.

Current climate variations have different levels of impacts on different regions of the continent. This is because the sub-Saharan region in particular encompasses a rich mosaic of ecological settings. JAGTAP and CHAN (2000) describe the different agro-ecological zones in the continent, the challenges (ecological production constraints) and the future prospects for agriculture. Overall, the comprehensive studies of NICHOLSON (1993, 1994) and HULME (1992, 1996) depict rainfall variability in the continent with different extent of variation in the different ecological zones. The four major ecological zones include the arid, semi-arid, sub-humid and moist Savanna, and the humid forest zones. Technological needs, agroclimatological information needs (better water management and early warning systems, pest and diseases) and growing demand for agrometeorology (better weather forecast, professional advice, combating wind damage) are also identified as some of the major challenges facing agriculture throughout the continent. With the exception of the East Africa Rift Valley system and southern Cameroon, the topography of the continent is relatively subdued (SOMBROEK, 1993).

Most African landscapes are characterised by densely dissected crystalline and sedimentary low uplands, interspersed with low plateau conserved by laterite caps, with few extensive areas of gently undulating and stone-free uplands with undisturbed soil developed over long geological time frame (*ibid*.). There are relatively many flat lowlands, e.g. around the coastal delta of River Niger, the Chad Basin and the Congo Basin. The soils are also very varied in nature (see FAO, 1991) with some rich, deep and stable soils, e.g. volcanic deposits of Mount Cameroon in Southwestern Cameroon and the Rift Valley (the Nitosols and Andosols of the highlands of Kenya, Uganda, Rwanda, Ethiopia, northern Tanzania). Some are strongly weathered (Lixisols, Acrisols and Ferralsols) (see OLDEMAN et al., 1991, and SOMBROEK, 1993). Sandy soils such as the Arenosols of the Sahelian zone, Botswana, Angola and northeastern Kenya, whilst the soils of the lowlands are varied, and range from sandy Podosols to heavy clay Vertisols (SOMBROEK, 1993). According to OLDEMAN et al. (1991) anthropogenic land degradation is having a toll on the continent causing water erosion to cover about 230 million ha, wind erosion affects 190 million ha, chemical degradation impoverishes 60 million ha, and physical degradation affects 20 million ha. STOORVOGEL and SMALING (1990) also report chemical degradation and gradual loss of nutrients. Fortunately, however, most of this degradation is in light-to-moderate form that can be recuperated.

In sub-Sahara as a whole agricultural exports make up 16% of total exports, while agricultural imports (mainly cereals) account for around 11 to 15% of total imports. However, during the past three decades, the continent has suffered massive losses from the erosion of its share of world trade, aggravated by substantially worsening terms of trade. This has negatively impacted on farm supply response for the continent's main agricultural export commodities of cocoa, coffee and cotton, and principal food staples. Figure 3 indicates the per capita production index of agriculture, cereals, field crops and livestock for sub-Saharan Africa. Agricultural output, in general, in the continent depicts slight declines in production. Because population increased by 3% per year per capita agricultural and food production appears to stagnate. However, despite aggregate food production struggling to keep pace with the rising population, food insecurity[4] remains persistent in some parts of the continent. This is not necessarily due to shortfalls in production, but for the most part due to the increasing paucity of rural and agricultural income[5]. National level reviews reveal that some nations in the continent increasingly rely on food imports to compensate for shortfalls in domestic production and escalating demand for food production and feed grain.

In the decade 1980-90 real agricultural production growth in sub-Saharan Africa was 2.3% per year (FAO, 1997a) and between 1991-2000 it averaged 2.5% per year, with food production increasing by 2.9% over the same period (FAO, 2002). Previous decline in agricultural production in the region recovered largely owing to strong expansion in Nigeria. Particularly good performance is also recorded in Angola, Ghana[6], Cameroon and Uganda whilst Ethiopia, Zambia and Zimbabwe witnessed declines estimated in the 3-5% range (FAO, 2000a). Sudan and the Democratic

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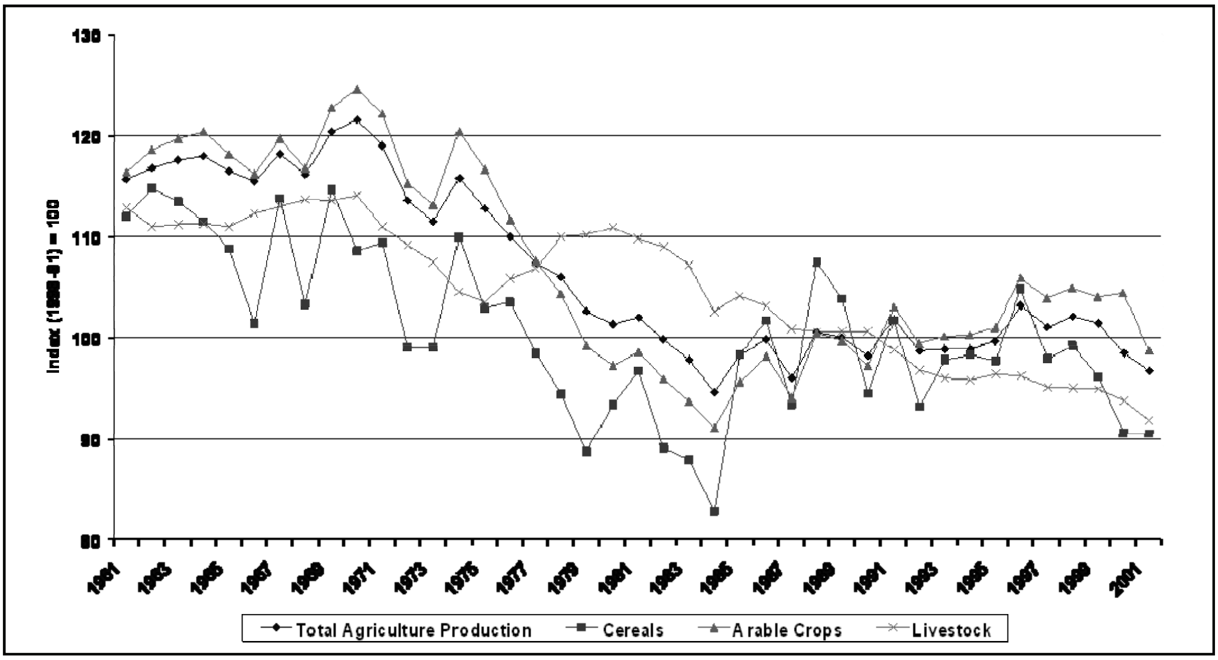
4 Food insecurity relates to individuals not having enough access to food to maintain a healthy and active life. MCCALLA (1999) identifies three critical dimensions for food security: (i) availability of food supplies, (ii) access to food in terms of income, and (iii) proper utilisation of food.

5 Approximately 16% of the region's population lives in countries that have an average GDP per capita of less than US$200; 36% live in countries with an average GDP per capita of less than US$300 and as many as 75% live in countries with an average GDP per capita below US$400 (DIXON et al., *ibid*.). In the region as a whole, an estimated 40% of the total population fall below nationally defined poverty lines.

6 Following sectoral reforms in the 1990s, the declining trade in export crops (e.g. cocoa) recovered and production grew at 8% per year, food crop production over the last decade grew at 4.1% per year (cassava) and other staples (plantain, cocoyams and cereals) at 3.0% per year. See FRIIS-HANSEN (2000).

Republic of Congo observe stagnating levels of production due to conflicts. Armed conflicts lead to the destruction of crops and livestock, deny access to land and water, displacement of human resources required for food production, disruption of infrastructure and markets, and the potentials for efficient distribution and safe consumption.[7] Without access to well-functioning markets for outputs and inputs capital and labour, the benefits from improved human resources and access to productive resources will not be fully captured by food insecure people.

Figure 3. Production indices in sub-Saharan Africa, 1961-2001



Source: FAO (2002)

Though, agriculture exports contribute about 45% of total exports in East Africa, however, in Tanzania[8], Kenya, Ethiopia, Somalia and Eritrea substantial food assistance is

7 In sub-Saharan Africa conflicts are caused primarily by poverty, greed, ineffective political institutions and 'bad governance'. Sudan is a country which could easily feed itself, were it not of the 20 year old civil war. Land is plenty and fertile and the River Nile presents opportunity for irrigation. However, Sudan is permanently food insecure, relying on food aid and handouts. In the Democratic Republic of Congo, fertile areas in the East of the country which used to produce surplus food marketed in cities in the west of the country, recently, production has been hampered by armed conflict, rendering access to main markets impossible.

8 The production of the four principal food crops (maize, paddy, wheat and cassava) grew by an average of 2.2% per year between 1990-97 (FAO, 1997b). With population growth rate during the same period estimated at 3.3% per year, short falls were made up by increased food import leading to a food import bill of US$ 194 million in 1995 (WORLD BANK, 1998).

often required due to drought-induced crop and livestock losses. Successive poor rains and intermittent drought seriously hampers food production in these states. In most pastoral areas, pastures and livestock are seriously affected, resulting in acute food shortages and migration. In Eritrea, Somalia and Ethiopia civil conflicts also disrupt agricultural production and marketing, causing food shortages and mass population displacements. In West Africa[9] and the Sahel region, food supply situation is fairly stable and markets fairly supplied. In some areas, floods and drought (Mauritania, Niger and Senegal) have hampered production. In the last decade, the principal export crops in Ivory Coast (cocoa and coffee) rebounded from the 1980s stagnation. Output of both crops grew following liberalisation and sectoral policy reforms with cocoa production increasing by 6.5% per year (FRIIS-HANSEN, 2000). Cereal crops averaged 4.6% per year growth rates in 1990-96 exceeding the 3.1% per year population growth rates (FAO, 1997a). However, recent political upheavals in the Ivory Coast seriously hampered the production and export of principal commodities. Similarly, in Liberia and Sierra Leone civil strife impeded production and rendered the states heavily depended on international food assistance. A similar scenario is observed in the Great Lakes region. Production of Uganda's main export food crops (banana, maize, wheat and oilseeds) averaged 1.1% growth rate during the 1990s. However with a population growth rate of 3.3% per annum during the same period, food deficits were observed. In Burundi and Rwanda, despite improvements in production, food shortages persist in some parts of the country. Reduced harvests have also been attributed to dry weather and civil strife. In southern Africa, where agriculture represents 14% of export, climatic constraints and other challenges impede agricultural production.[10]

Overall, production estimates indicate that sub-Saharan Africa compares fairly favourably with North Africa and the transition countries in Eastern Europe, but less favourably with Asia, the Pacific region, the Caribbean and Latin America (FAO, 2004).. However, farmers in sub-Saharan Africa have increased production by cultivating more land, and not by increased use of modern inputs such as fertiliser or improved crop varieties. Although the Green Revolution did much for agriculture in Asia and Latin America, it has been less successful in sub-Saharan Africa, and yields have mildly changed in forty years.

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9 West African agriculture makes up 10% of the sub-region's exports. However, agriculture's contribution to export earnings has declined steadily over the past three decades due to expansion of the petroleum industry.

10 In Mozambique, South Africa, Botswana and Swaziland the worst floods in 40 years struck in February 2000, leaving tens of thousands homeless and causing considerable damage to infrastructure. In southern Africa agriculture's contribution to export earnings has steadily declined due to expansion of non-agricultural sectors.

Productivity gains achievable from conventional technologies have not been fully exploited. High yielding rice and wheat varieties have been researched in international agricultural research centres. Farmers in high potential environments such as Cameroon who have relatively better access to modern farming inputs, however, often lack the agronomic and crop management technologies and knowledge that are crucial for bridging the gap between experimental yields and those in farmer fields (MOLUA, 2003).

Following changes in the global economic environment, economies in the continent are faced with economic policy shifts. Reductions in aid availability, rising debt service requirements, falling commodity prices and slow economic growth have pushed for policy reforms. The Structural Adjustment Programmes (SAPs), Enhanced Structural Adjustment Programmes (ESAPs), Poverty Reduction and Growth Facility (PRGF) and Heavily Indebted Poor Country Innitiatives (HIPC) pushed by the IMF and World Bank have had a major impact on growth strategies, competitiveness and the performance of public sector organisations, including research institutes. Fiscal reforms have result in cutbacks in research outlays and resource allocation for research centres (see BONTE-FRIEDHEIM et al., 1993).

4. Impact on productive capacity of African agriculture

4.1 Analytical framework and data generation[11]

4.1.1 Empirical analysis

Socio-economic cross-sectional information is obtained for Burkina Faso, Egypt, Kenya and South Africa. This information is fitted into a revised Ricardian model (GBETIBOUO and HASSAN, 2005; KURUKULASURIYA and MENDELSOHN, 2006). According to the Ricardian model climate changes the production function of crops through fluctuations in temperature and precipitation (MENDELSOHN and DINAR, 2003). Farmers take into account these fluctuations and adjust inputs accordingly. The production factors include commercial (land, different inputs) and non-commercial factors, such as climate, quality of soils and irrigation. The rationale is that cross-sectional observations across different climates can reveal the climate sensitivity of farms. The advantage of this empirical approach is the inclusion of the direct effect of climate on productivity and adaptation responses by farmers to local climate. This approach makes it possible to compare the sensitiveness of different regions to climate

[11] For data generation and empirical modeling for Kenya (see KABUBO-MARIARA and KARANJA, 2006), Egypt (see EID et al., 2006), Burkina Faso (see OUEDRAOGO et al., 2006) and South Africa (see BENHIN, 2006).

change by connecting the inter-regional differences in the climate to the differences in land values and farm returns. We thus assume that farmland net revenue (R) reflects the net productivity and costs of individual crops and livestock, and implicitly technically related as:

$$(1) \qquad R = \sum P_i Q_i (X, F, H, Z, G) - \sum P_x X$$

where P_i is the market price of crop i, Q_i is output of crop i, X is a vector of purchased inputs (other than land), F is a vector of climate variables, H is water flow, Z is a vector of soil variables, G is a vector of economic variables, and P_x is a vector of input prices. The farmer is assumed to choose inputs (X) to maximize net revenues given the characteristics of the farm and market prices. Each farmer is assumed to choose inputs and outputs to maximize their net revenue subject to the climate and soils of each farm, in addition to other key economic variables. The observed net revenue function is therefore the locus of maximum profits given the set of exogenous climate, soil, and economic conditions. The standard Ricardian model relies on a quadratic formulation of climate:

$$(2) \qquad R = \beta_0 + \beta_1 F + \beta_2 F^2 + \beta_3 Z + \beta_4 G + \beta_5 \log(H) + \mu$$

where μ is an error term. Both a linear and a quadratic term for climate, F (temperature and precipitation) are introduced. This quadratic functional form for climate captures the expected nonlinear shape of the relationship between net revenues and climate (MENDELSOHN, NORHAUS and SHAW, 1994; MENDELSOHN, SANGHI and DINAR, 2001). Based on agronomic research and previously reported cross-sectional analyses, farm net revenues are expected to have a concave (hill-shaped) relationship with temperature (MENDELSOHN and DINAR, 2003; GBETIBOUO and HASSAN, 2005; KURUKULASURIYA and MENDELSOHN, 2006). For each crop, there is a known average temperature that is best for crop production, but this relationship is not necessarily concave for each season.[12] The marginal impact of a single climate variable, fj, on crop or livestock net revenue evaluated at the mean of that variable is:

$$(3) \qquad E\lfloor \partial R / \partial f_j \rfloor = \beta_{1,j} + 2\beta_{2,j} E\lfloor f_j \rfloor$$

These marginal effects can be evaluated at any level of climate or flow, but the focus is on showing effects at mean climate levels for Africa. Note that the linear formulation of the model assumes that the marginal effects are independent of future technological change. However, it is possible that future technological change could

[12] Seasons were defined as follows: winter is defined as May, June, and July; spring as August through October; summer as November through January, and fall as February through April.

make crops and farming activity more susceptible to temperature or precipitation changes - or less so.[13]

4.1.2 Farm and household data

About 4,000 farming households in the administrative districts of the four countries are studied and information collected that allows for the estimation of net farm revenues for winter and the summer seasons. A data base is generated with information on crop production, livestock, household characteristics, employment, type of crops grown, the area of land planted, the quantities harvested and sold, and various costs incurred for seeds, fertilizer, pesticides, light, heavy and light and heavy machinery and animals used in agricultural work; and farming related buildings. Farmers' access to information for farming activities and the sources and cost of this information, estimate of the farm household's total income for both farming and non-farming activities, taxes paid and subsidies received and farmers' perceptions of short- and long-term climate change and their adaptation strategies in response to these are generated and used for analysis.

4.1.3 Climate data

Climate data on satellite temperature and ARTES precipitation (wetness) are used. The satellite data comes from the USA Department of Defense (BASIST et al., 2001). The African Rainfall Temperature Evaluation System (ARTES) data is created by the National Oceanic and Atmospheric Association's (NOAA) Climate Prediction Centre of the USA (WORLD BANK, 2003). The ARTES data is based on ground station measurements of precipitation, minimum temperature, and maximum temperature.

4.1.4 Climate change projections

General circulation models based on climate change scenarios as input to a water balance model is employed to provide insights into the changes in hydroclimatic variables that can be expected under different climate change scenarios (STRZEPEK and MCCLUSKEY, 2006). The scenarios represent a range of equally plausible future climates (expressed as anomalies of the baseline 1961–1990 climate) with differences attributable to the different climate models used and to the different emission scenarios that the world would follow. Three main scenarios derived from CSIRO2, HadCM3 and PCM in conjunction with the A2 and B2 emission scenarios. Consequences of

[13] The strength of the Ricardian method is that it captures the adaptation responses of farmers. The use of net revenues in the analysis reflects the benefits and costs of implicit adaptation strategies. Specifically, the analysis incorporates the substitution of different inputs and the introduction of alternative activities that each farmer has adopted in light of the existing climate.

these climate change scenarios on net crop revenues are estimated. The predicted changes for temperature and precipitation plus the impacts on crop net revenues for 2050 and 2100 are revealed. All three models predict increased temperatures by 2050, and even higher levels by 2100. All three models also predict falls in precipitation by 2100.

4.2 Country findings and discussion: a tale of four countries

4.2.1 Kenya

Impact of current climate on productive capacity

In Kenya, high summer temperatures are harmful to crop production while high winter temperatures are beneficial. This is because summer (March–May) is the planting period followed by formative crop growth, while winter (June-August) is the period for ripening and maturing of crops. High summer temperatures, therefore, slow down or destroy crop growth, while higher winter temperatures are crucial for ripening and harvesting (KABUBO-MARIARA and KARANJA, 2006). In the Kenyan highlands, winters are quite chilly and excessively low winter temperatures have been associated with crop damage from frost. However, excess winter temperatures would be harmful for crop productivity. Summer temperatures exhibit a U-shaped relationship with net crop revenue and winter temperatures a hill-shaped one. Both fall and summer precipitation are, however, positively correlated with net crop revenue and exhibit a hill-shaped relationship with it. The results further show that climate exhibits a non-linear relationship with net revenue, which is consistent with the available literature (MENDELSOHN et al., 1994, 2003). Most of the household level variables have a significant impact on crop revenue. Livestock ownership dummy, farm size and wage rates are inversely correlated with crop revenue. Farm size exhibits a U-shaped relationship with crop revenue, implying that large farm size may be associated with higher productivity. Main and secondary occupation of household head, religion of household head and average number of years of education of the household members are positively correlated with net crop revenue. Household size, introduced as a proxy for household labor (or remotely population density) has a positive and significant impact on net crop revenue Livestock ownership dummy has a negative and significant impact on net revenue. This implies competition rather than complementarity between farming and livestock keeping. Irrigation has a large positive impact on crop revenue, implying the importance of adaptations to counter the impact of climate change.

Marginal impact of climate

The marginal impacts for winter temperatures are positive, but summer temperatures have larger negative impacts on net crop revenue. Using a climate only model, crop revenue is inelastic (-0.55) with respect to changes in temperature. Summer temperatures are statistically significant and thus different from zero, but the impacts for winter are insignificant. Using the model with all variables, the elasticity of crop revenue with respect to changes in temperature falls drastically in absolute terms (from 0.55 to 0.071). These results show that high temperatures are harmful for productivity (elasticity is negative), confirming that global warming is likely to have devastating effects on agriculture unless farmers take adaptation measures to counter the impact of climate change (KURUKULASURIYA and MENDELSOHN, 2006). The marginal impacts of precipitation are more modest than for temperatures, but the elasticities are higher. Crop revenue is highly elastic with respect to changes in precipitation, and increased precipitation increases productivity. A 1% increase in rainfall would lead to a 3.25% increase in net crop revenue, though a similar change in temperature would lead to only a 0.07% fall in revenue.

Projected impact of global warming

The climate models predict an average increase in temperature of 3.5°C and 4°C, respectively, with the doubling of CO_2 by the year 2030. Estimates show that there has been a tendency for annual rainfall to decrease in the arid and semi-arid areas and increase over Lake Victoria and the coastal and neighboring regions. This implies that some regions may gain from global warming while others may be adversely affected. The models studied predict, however, that on average, Kenya will experience a 20% decrease in rainfall by the year 2030. With precipitation remaining the same, changes in temperature predicted by the CCC model would result in a 1% (US$3.54 per hectare) gain in high potential zones but a 21.5% (US$54 per hectare) loss in medium and low potential zones. The results further suggest that medium and low potential zones will bear the brunt of global warming in Kenya. Using the GFDL model, losses are estimated to about US$178 per hectare by the year 2030 for these zones compared to losses of only US$32 for high potential zones and US$117 for the whole country. These results mean that a small increase in global warming would have immediate adverse effects on already dry areas. This is what is happening to Kenya at present because of prolonged drought in the arid and semi-arid areas which have already claimed lives of both human beings and livestock, yet the effect is still not pronounced in high potential zones. The results confirm that long-term climate change has important implications for agriculture. The results further show that medium and low potential zones are likely to suffer more from rising temperatures due to global warming than from a fall in precipitation. However, the reverse is the case for high potential zones and this may be because such zones are located in the highlands where temperatures are quite low and so a rise in temperature may have a lower impact than a fall in precipitation. The whole country is also expected to suffer more from decreases in rainfall than from rising temperatures, just as in medium and low potential zones.

4.2.2 Egypt

Impact of current climate on productive capacity

The linear and quadratic terms of both spring and fall temperatures have a U-shaped relationship with farm net revenue (EID et al., 2006). Spring is when winter crops develop their seeds and any rise in temperature can consequently reduce the yield. Similarly, the temperature in the fall is still relatively high, particularly in September and October, when summer crops develop their seeds, so any increase could reduce revenues. Results also showed that winter and summer temperatures have an inverse U-shaped relationship with crop area per net revenue. The inverse U-shaped relationship between summer temperatures and net revenue is not expected, given that summer temperature is already hot. The results also show that winter and summer temperature negatively affects net revenue, as does the quadratic term of spring and fall temperature. Farm size, household size, distance to nearest market to buy input, amount of crops sold and quantity of light machinery positively affected net revenue, whereas total cost for labor per farm and amount of crop consumed by livestock negatively affected it.

Marginal impact of climate

An increase in temperature of 1°C is expected to reduce net revenue by $968.94 per hectare without livestock and by $1,044.28 per hectare when livestock is in the farming mix. Irrigation reduces the harmful effect of increased temperature and increases net revenue by $26.17 per hectare without livestock and reduces it by $1,680.14 per hectare when livestock is included. Irrigation is shown to reduce the harmful effect of increased temperature and simultaneously increases net revenue by $150.96 per hectare without livestock and decreases it by $1,412.41 per hectare when livestock is included. The option of raising livestock on farms as an adaptation for coping with the harmful effect of increased temperature was not effective. In fact, it increased the losses in farm net revenue. This might be attributed to the fact that many of the farmers in the survey were smallholders, who could not afford to use part of their small area to raise livestock.

Projected impact of global warming

The results suggest that temperature increases of 1.5°C or 3.6°C will significantly reduce farm net revenue per hectare. The reductions in net revenue are $1,453.41 and 3,488.18 per hectare for increases of 1.5°C and 3.6°C, respectively, if adaptation is not incorporated. However, reductions in net revenue could be less severe if farmers used more heavy machinery on their farms. The reductions in net revenue are $116.67 and $280.01 per hectare for 1.5°C and 3.6°C increases respectively, showing that expenditure on farm machinery could reduce the harmful effect of temperature increase. Irrigation could increase farm net revenues by $39.26 and $94.21 per hectare for 1.5°C and 3.6°C increases, respectively, and by $226.44 and $543.46 per hectare for 1.5°C and 3.6°C increases, respectively.

4.2.3 Burkina Faso

Impact of current climate on productive capacity

Seasonal climatic variables strongly impact crop outputs in Burkina Faso. The relationship between revenue and temperature or precipitation is revealed to be non-linear. This means that temperature or precipitation affects the net revenue positively up to a certain level, above which it causes damage to the crops (OUEDRAOGO et al., 2006). The effect of the hydrologic variable on net revenue is also non-linear. The precipitation and the runoff are significant. This means that water is an important factor that explains the spatial variation of revenue in Burkina Faso. The effects of the soils are negative, which can be explained by the low fertility level and low water retention capacity of the soils in Burkina Faso. Agriculture in Burkina Faso is small-scale rain-fed. To compensate for low productivity, farmers increase the area under crops. Although this strategy helps increase the total quantity of produce harvested, it is not efficient because it decreases yield generally. Most of the time farmers do not have the capacity to manage large areas. This explains why farmland size has a negative effect on revenue. The household size affects revenue positively. Because the agriculture is extensive, the size of household is important to supply sufficient labour. As expected, extension service helps improve net revenue. Irrigation has a positive effect on revenue. As a way of adapting to climate change, it is practiced during the dry season and provides farmers with some additional income. During the rainy season it helps to alleviate rainfall hazards and ensure stable production.

Marginal impact of climate

The marginal effect of temperature for farms in Burkina Faso is calculated on the basis of the average temperature of the sample, which is 26°C in the rainy season and 26.6 °C in the dry season. The marginal effect of the precipitation is calculated on the basis of the average annual precipitation of the sample, which is 717mm in the rainy season and 80mm in the dry season. No significant difference is observed between the average temperatures for rainfed and irrigated crops. However, precipitation figures for rainfed farms are slightly higher than for irrigated ones for any season. This difference suggests that irrigation is practiced where it is necessary because of lower rainfall, but we see that its development depends on the hydrological potential of the region. Therefore, most of the drier areas which have water resources develop irrigation. The marginal effect of precipitation is significant at the threshold of 1% while the marginal effect of temperature is significant at 10% for the model with adaptation. This model shows that if the average annual precipitation increases by 1mm, agricultural incomes will increase by US$2.70/ha on average for all the farms in the sample. The increase will be US$2.56/ha for rainfed farms. The increase will reach US$3.51/ha for farms which have not adopted certain adaptation strategies. This means that the farmers' current practices mitigate the effect of climatic variability. On the other hand, if the average temperatures increase by 1 °C the net agricultural incomes will drop by US$19.90/ha for the model with adaptation. This fall in income is weaker for the model without adaptation (US$11.5/ha) but remains non-significant. The effects of climate on income are slightly mitigated in strictly rainfed zones. This means that the rainfed farms are less vulnerable to the effects of climatic changes, because they integrate the climatic risks better and take enough precautions to protect their incomes. With regard to the elasticity of the climatic variables, we can say that agricultural incomes are very sensitive to variations in precipitation (including irrigated farms).

Projected impact of global warming

The A2 and B2 emission scenarios forecast a rise in temperatures for Burkina Faso. These rises will vary from 2.4°C to 3.9°C in 2050 and from 5.7°C to 9.7°C in 2100 for the A2 scenario. The B2 scenario envisages increases of between 2.4°C and 3.8°C in 2050 and between 4°C and 7.1°C in 2100. Four of the five models predict an increase in precipitation from 1% to 12% in 2050 and from 3% to 30% in 2100. Only one model foresees a decrease in precipitation of about 4% in 2050 and 9% in 2100. According to the cs-a2 model, farmers will lose 72% of their income in 2050 and 177% in 2100 following the increase in temperatures. The decrease in precipitation predicted by this model will result in a reduction in farm households' income from 84% in 2050 to 190% in 2100. The cumulative effect of the two factors will be dramatic for the farmers who will experience the total erosion of their incomes by the 2050s. With regard to the other models (ec-a2, ec-b2, ha-a2 and ha-b2) the increases in the temperature certainly lead to a reduction in incomes but at the same time the increases in precipitation lead to a rise in incomes. The loss of income is thus compensated for by the profits generated by the increase in rains. For example, according to the ec-a2 model, the farms will lose 61% of their income in 2050, but at the same time the increases in precipitation predicted by this model will increase incomes by 253%. The combined effect will be positive for incomes. If things evolve this way, rainfed agriculture would adapt better than irrigated agriculture in Burkina Faso. Indeed, irrigation is practiced only for specific crops such as rice and for truck farming in small areas in the dry season. If the increase in precipitation relates only to the rainy season (undoubtedly), it will be useful for the irrigated system only through the filling of dams and the re-supplying of ground waters. However, rising temperatures especially during the dry season will increase the crops' demand for water.

4.2.4 South Africa

Impact of current climate on productive capacity

Climate variables have significant influences on crop net revenues in South Africa. To a large extent there is a non-linear relationship between climate variables and crop net revenues. Summer temperatures show an upward trend, fall temperatures show a downward trend, and winter and spring temperatures are hill-shaped That is, higher temperatures in winter and spring will be beneficial up to a certain extent point, after which the benefit will be negated. Precipitation for summer, fall and winter is U-shaped, while for spring it is U-shaped (BENHIN, 2006). Climate variables in the irrigation model follow the same trend as the full sample model except for the fall temperature which is hill-shaped. Except for winter and summer temperatures and fall precipitation, the effects of the other climate variables in the dryland model are different from the full sample and the irrigation models. This is expected given that the responses of irrigated farms and dryland farms to climate are expected to be different. In the dryland model, spring temperatures show a downward trend, summer precipitation is U-shaped, winter precipitation shows an upward trend, and spring precipitation has an inverse relationship with crop net revenues. It is important to note that while most of the climate variables, especially for precipitation, are significant in the dry land farm models, only the summer temperatures are significant in the irrigation model. This may be because dry land farms rely heavily on climate variables as they lack substitutes for rain water, while irrigation helps to reduce the effect of climate variables on farming activities. Comparing the large-scale and small-scale farms, climate variables in both models follow a trend more or less similar to the full sample model, with a few differences. In the large-scale model, except for summer, winter and spring temperatures, the trends in the other climate variables are different from the full sample model. The trends in all the precipitation variables, though not significant, are different from those of the full sample model. Summer and winter precipitation shows an upward trend, while the fall and spring precipitation show a downward trend. For the small-scale farm model, the climate variable trends are similar to those of the large-scale farms except for the fall precipitation which is hill-shaped. The similar trends in the climate variables in both large-scale and small-scale farms are due to the influence of irrigation and dryland farms. This suggests that whether a farm irrigates or not is more relevant to climate analysis in South Africa than the scale of the farm. In general, climate variables are very relevant for crop farming activities in South Africa, and particularly for dryland farming.

Marginal impact of climate

The marginal effects of a 1°C increase in temperature on crop net revenues for different types of farmers in South Africa, temperature increases in the summer farming season would have a negative effect on crop net revenues for all types of farms in the country. More importantly, higher temperatures in the fall will not augur well for crop farming. On the other hand, increases in temperature in the winter farming season will positively affect crop net revenues. The net effects of the seasonal impacts indicate that a 1°C increase in annual temperatures will lead to an increase in crop net revenue of US$80 for the whole country, US$191 for irrigated farms, US$588 for large-scale farms and US$60 for small-scale farms. However, dry land farms will see a fall in their net revenues by about US$50 per hectare. Estimated elasticity indicates that a 1% increase in temperature will lead to 4% increase in net revenues for the whole of South Africa, 7% for irrigated farms, 27% for large-scale farms, 4% for small-scale farms, but a fall of 5% in net revenues for dry land farms. With adaptation, the net effect of a 1°C increase in temperature on net revenue increases from US$80 to US$124, and for irrigated farms from US$191 to US$259. For dry land farms the inclusion of adaptation related variables rather aggravates the negative effects of increased temperature, with the annual negative effects increasing from -US$50 to -US$68 with an elasticity of -7.25. What this indicates is that though adaptation is important in controlling adverse climate effects, if they are not properly implemented they may rather aggravate the problem

Increases in precipitation leads to increases in net revenues for all the types of farms except for small-scale ones, with more significant impacts for dry land farms. Again the relative seasonal impacts are important. The summer farming season, surprisingly, indicates that increases in precipitation affect net revenues negatively. This is mainly due to the strong negative influence of the fall period. The implication is that the timing of rainfall is important for agricultural activities. Early rainfall in the summer farming season would be more beneficial to crop farming than later rainfall in the fall season. Therefore, shifts in the timing of the rainfall as a result of climate change may be damaging to crop activities unless farmers are aware of these shifts and adjust their farming activities appropriately in the summer farming season. Except for dry land farms, the influence of increased precipitation in the winter season would be positive. The annual estimates indicate that an annual increase of 1mm/month of precipitation will have a positive effect on net revenues, with the exception of those of small-scale farmers, which indicate a negative value though not a significant one. As expected, dry land farms benefit more, as indicated by the significance of their positive effects and relative estimated high elasticity of 7. For the country as a whole, an annual net gain of US$2 is expected with a 1mm/month increase in precipitation: US$29 for irrigated farms and US$25 for large-scale farms, but -US$28 for small-scale farms, with corresponding elasticities of 0.37, 3.12, 3.25 and -6.9. It follows that a decrease in precipitation by the same amount will reduce net revenues by similar amounts. Including adaptation variables seems to have had a positive effect for both irrigated and dry land farms and significant for the latter. The results indicate that a 1mm/month increase in precipitation will now lead to increases of about US$17 and US$11 in crop net revenues for irrigated and dry land farms, respectively.

Projected impact of global warming

Comparatively, dry-land farms will be more affected by increased temperatures and decreased rainfall. Comparing large- and small-scale farmers, the latter will also be more affected. For 2050, given the A2 scenarios, crop net revenues are expected to fall by US$5.14 to US$16.26 (or 1.7% to 5.3%) per hectare for the whole of South Africa, US$5.34 to US$20.23 (or 1.2% to 4.3%) for irrigated farms, US$41.63 to US$55.24 (or 26.2% to 27.7%) for dry-land farms, US$20.65 to US$49.39 (or 5.8% to 13.8%) for large-scale farms, and US$25.05 to US$204.60 (or 9.9% to 20.7%) for small-scale farms. The negative effects are expected to increase by 2100, with a fall in crop net revenues ranging from 9% to as high as 90%, with small-scale farms to be most affected. The least to be affected are irrigated farms. This also indicates the crucial positive effects of irrigation as a cushion for adverse climate effects. Adaptation strategies, if properly implemented, are expected to reduce the negative impacts of the climate scenarios on crop net revenues, especially with respect to temperatures.

5. Implications for resilience and sustained productive capacity

According to the findings of the four-country survey, it is clear that there is a significant impact of climate change on farm returns and a difference between the impacts of climate on irrigation and dryland farms. However, the differences between the impacts on large-scale farms and small-scale farms are not very clear-cut, because they are overshadowed by the impacts of whether a farm is irrigated or not. Climate impacts are observed to have a non-linear relationship with net revenue. That is, increases in climate variables, especially for precipitation, will be beneficial to crop farming but beyond a certain limit the impacts will be negative. More important are the relevance of socio-economic or adaptation related variables in controlling or worsening climate effects. Access to markets would cushion farmers against adverse climate effects. Easy accessibility of markets means relatively higher prices for farm products and therefore helps cover additional costs caused by the adverse effects of climate. More interestingly, is the limited significance of extension service on farm returns.

These findings come on the backdrop of farmers' perception that increased temperature and changes in precipitation, such as the reduced volume of the rainfall, shift in the timing of the rainfall and the shortened period of the rain, is increasing. Given this perception, and depending on the farming system, farmers have adopted several coping mechanisms which could be categorized into six main types: (i) adjustments in farming operations, (ii) increased chemical application, (iii) irrigation, (iv) provision of shelter and shade for crops, (v) soil conservation practices and (iv) insurance policies and other sources of income to cover their risks. However, the most common adaptation options across all types of farming activities in the continent in response to higher temperatures and lower rainfall are adjustments in farming operations, specifically changes in the variety of crops and livestock breeds, and increased irrigation.

This micro-level analysis and reality imply macro-policy shifts associated with climatic shocks will in the years ahead intensify macroeconomic effort that will ensure not only better management of inflation and interest rates, but also restructuring and better management of the tax system to enhance adaptation at farm, regional and national levels. Lower rates and fewer distortions in the tax system makes it easier to administer and more efficient and equitable, and enhances the potential of economic agents in the agricultural sector to factor costs in production distribution and marketing plans. Macro-policy adjustments will in addition require increased liberalization of the financial system and an implementation of agriculture civil service reforms for better performance of the extension service. The observations in the country level surveys reveal a need for improved data monitoring at all levels as a basis for economic policy and the need for strategic interference in agriculture via targeted subsidies, insurance and material assistance. Resilience and stronger response of the agricultural sector for the countries studied will require diversification and promotion of agricultural exports, more especially the promotion of non-traditional exports. This will further require the tacit reduction in 'aid dependence' and elimination of agricultural products dumped to the detriment of local producers in markets across the continent.

In general, these observations have several policy implications for the way climate change could be managed so as to reduce the damage to the crop farming sector. Policies are needed, that will call for new budgting and revised government spending directed at taking advantage of the gains and reducing losses by identifying and assessing the efficiency of current coping mechanisms and finding ways to support them. For instance, there is need to build more dams and increase the capacity of existing ones to provide for irrigation and energy. But increasing water scarcity will mean more government expenditure and prioritization of science, as research needs to be done into new crop varieties and new animal breeds that are heat tolerant and less affected by water stress. Further related to new crop varieties is improved technology and access to markets, both local and international. Proper and efficient extension services are required. Land reforms particularly in South Africa will be needed to address the complexities of environmental change, especially the effects of long-term investments, for example, in irrigation and heavy machinery, which are identified as crucial for controlling climate effects.

6. Concluding remarks

Agriculture will continue to be the backbone of Africa's economic development for the foreseeable future, accounting for most of the foreign exchange earnings. Further agricultural progress is the key not only to food security but to rural and national prosperity, as well. Therefore, given the agrarian nature of African economies, the essential precondition for overall social and economic growth in the continent is a determined agricultural sector brought about by a steady increase in agricultural productivity, assisted by sustained adaptations to climatic constraints. In order to make meaningful impact on poverty, structural weaknesses and human and institutional capacities in the continent broad economic and agricultural sector policies must begin factoring the expected constraints of global warming and climate change. The success of efforts to improve productive capacities to ensure sustained growth and benefits from globalization is critically dependent on overcoming the structural impediments and supply-side constraints in African agriculture compounded by environmental factors and climate change. Strengthening productive capacities in African agriculture will without doubt contribute to enhancing food security, human capital and wealth creation, which in turn will reduce poverty and increase employment opportunities. This will also enable economic agents in the sector to better utilize the trading opportunities arising from multilateral and regional trade liberalization. In the context of climate change, the agricultural sector will require resilient macroeconomic conditions, conducive regulatory environment, and adequate physical and social infrastructure to enhance its productive capacity. The future of agroeconomic development in the region will, therefore, be determined by the willingness of national governments, International Non-Governmental Organisations (INGOs), local Non-Governmental Organisations (NGOs), International Agriculture Research Centres (IARCs), National Agriculture Research Centres (NARCs) and outside donors to commit themselves to long-term effort and agendas for empowering farming communities.

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