African Adaptation to Climate Change from the Viewpoint of Green Revolution II

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Abstract

One fundamental question is how climate change adaptation can be fitted into the development and planning process and an important task lies in understanding the full scope of its implications. Climate change will affect African agriculture in particular. Adaptation pathways for climate change suggest greater net benefits at a local level than a global level; it is therefore considered that adaptation is an attractive instrument in Africa. Resilience-based actions play a major role in adaptation of African agriculture, and these actions basically overlap with the concept of the green revolution (dubbed Green Revolution II). The results from a model run based on this concept indicates that climate change influences technology progress and spread, and that technology progress and spread influence the climatic effects on agricultural output.

Keywords: Africa, agriculture, climate change, job creation, resilience

1. Introduction

Scientific and policy emphasis has focussed on mitigation efforts (i.e. the diminution of greenhouse gas emissions), but planned adaptation has come out as a countermeasure against to the negative effects of climate change (Martens et al., 2009; Schipper et al., 2008). Of the mainstream actions, mitigation is relatively mature in comparison with adaptation, though new instruments continue to be developed and introduced. Mitigation is fundamental to maintain negative effects of climate change as low as possible, and adaptation is also important because the negative effects are inevitable (Intergovernmental Panel on Climate Change [IPCC], 2009). In 2007, the United Nations (UN) Conference on was opened in Bali (Indonesia), and this conference announced the approval of an adaptation financial system to support developing countries that lack the economic, technological and human resources to tackle climate change problems (United Nations Framework Convention on Climate Change [UNFCCC], 2007); however, climate change adaptation is a multifarious subject that includes a lot of challenges (Schipper et al., 2008). Indeed, one fundamental question is how climate change adaptation can be fitted into the development and planning process. One important task lies in understanding the full scope of its implications (Schipper et al., 2008).

A comprehensive approach is considered necessary to achieve this task. For example, the joint framework between the United Nations Development Programme and the government of Japan has recently launched a programme for combining climate change with chances of country development; this programme also aims at comprehensive approaches to climate change adaptation in Africa (United Nations Development Programme [UNDP], 2009). Focusing on African agriculture, this manuscript attempts to paint a picture that will aid understanding of the link between strategic choice and agriculture development in the current climate change measures.

Roughly speaking, a third of the labor force is unemployed and/or lives below the poverty level in the world (International Labour Organization [ILO], 2001; 2006). Agriculture makes up about 15% gross domestic product (GDP) and about 30% employment in Africa (ILO, 2001), so agricultural development is essential to improve crop production as well as an employment rate and an income amount in African countries. However, poor formers will be subject to the climate change impacts because they depend on agriculture and have low ability to adapt (World Bank, 2008).

2. Scale and Region

The success of global mitigation initiatives to date is questionable and the efficiency of such action is also debatable (cf. Martens et al., 2009). More integrated climate strategies will be required to incorporate a wider range of mitigation, adaptation and vulnerability considerations (Klein et al., 2007; Wilbanks & Sathaye, 2007).

The FAIR model is an interactive, decision-support tool for analysing environmental and cost implications of climate mitigation regimes for future commitments for reducing emissions of greenhouse gases (den Elzen & Lucas, 2005). Under default settings of this model, the simulation results for the period 2005-2200 (see also Figure 1) indicate that the discounted costs of climate change impacts are ~2.5% amount at a discount rate to ~4.5% of global GDP in the baseline case; there is a difference within the range of 0.5% of GDP among the three choices – mitigation only, adaptation only, and a combination of mitigation and adaptation.

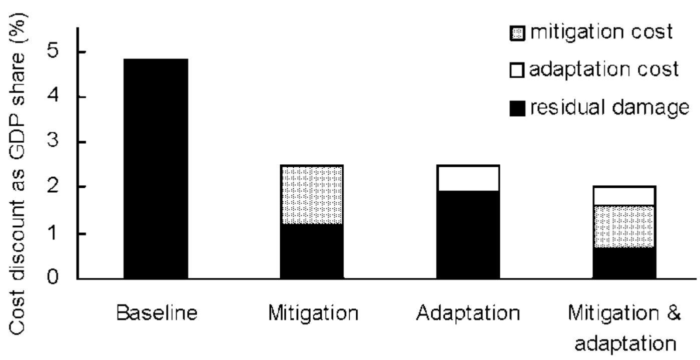

Figure 1. 2000-2200 estimates based on FAIR model: mitigation costs, adaptation costs, and residual damages due to climate change as share of GDP (adapted from Hulme et al., 2009)

The success of an adaptation action can be discussed to be dependent on its efficiency in achieving desired goals, as well as on subjects of impartiality and recognized legality of strategy (Adger et al., 2005). However, a number of features require to contemplate the project evaluation and public policy matters associated with climate change, cost analysis and benefit estimation; furthermore, realistic appliance of conventional cost-benefit theory to the climate change problem is hard because there are the global, regional and intergenerational character (IPCC, 1995).

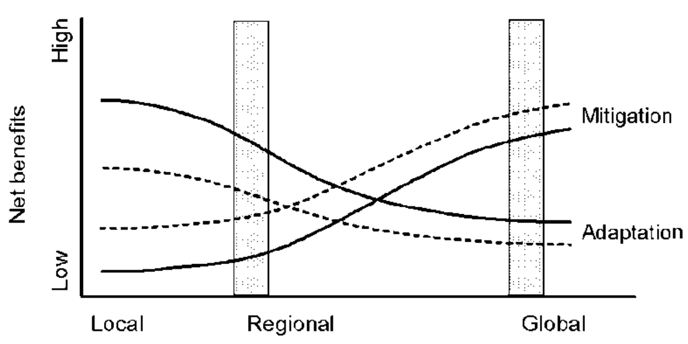

Figure 2. Conceptual cost-benefit comparisons between mitigation and adaptation (redrawn from Wilbanks et al., 2007). The solid line represents relatively moderate climate change, and the dotted line represents relatively substantial climate change

Preliminary findings from an integrated analysis (Wilbanks et al., 2003) indicate that both adaptation and mitigation are geographically dependent on the scale and qualitatively dependent on the forecasted degree of climate change. As illustrated theoretically by the bold lines in Figure 2, mitigation pathways demonstrate greater net benefits at a global level than a local level because various economic merits of mitigation investments are outside a local region; on the other hand, adaptation paths indicate greater net benefits at a local level because considerable impacts at a global level are difficult to mention through adaptation: e.g. sea-level rise, low-lying coastal zone, etc.

3. Climate Change and African Agriculture

Agronomic investigation studies the impact factors of climate change on specific crops (e.g. maize, wheat, rice, etc.) and assumes broad environments with a changed climate. The obtained results indicate that high temperatures linked with climate alteration will be risky in producing diverse crops (review in Adger (2001)). For example, the negative effect of climate change on maize cultivation is illustrated in Figure 3. It follows from this figure that climate change will affect African and South Asian agronomy in particular. A worst-case scenario of African agriculture indicates that the maize yield and the millet yield will decrease by 65% and 79%, respectively (Reilly et al., 1996). Not only higher average temperatures but also other factors such as intense droughts and floods will come down to productivity losses to crops and livestock. The sea level rises; consequently, there is a possibility that agriculture may be injured by flooding effect and salinisation of surface water and groundwater. Furthermore, less rainfall will decrease the water availability in irrigation and livestock production (World Bank, 2008). It is estimated that 75-250 million African people are subject to the above-mentioned water stress (World Bank, 2008).

4. Combination of Climate Change Strategy with Agriculture

Some remarks are given as follows: (i) agricultural development is important to improve crop production, unemployment and income in African countries (section I); (ii) adaptation reduces this cost substantially to ~2.5% by 2200, as compared, the mitigation-only scenario results in a discounted cost of 2.0% GDP by 2200 (cf. section II and Figure 1); (iii) adaptation paths represent greater net benefits at a local level (section 2); and (iv) climate change will affect African agronomy in particular (section 3 and Figure 3).

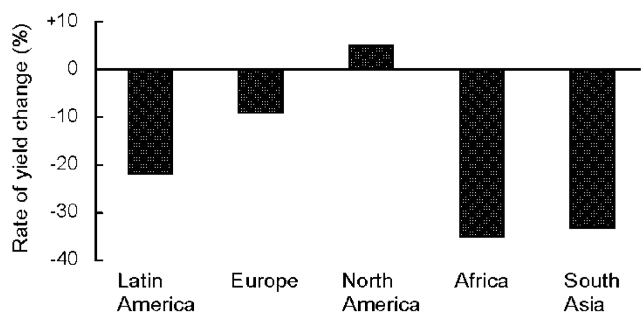

Figure 3. Impact of climate change on maize production by region (redrawn from Reilly et al., 1996). Estimates are based on an equilibrium change with a CO_2 doubling in the atmosphere from pre-industrial levels, and rates of yield variation represent the mean value

Therefore, agriculture is mainly discussed in order to indicate a comprehensive approach to a combination of adaptation with development in Africa.

4.1 Resilience

It follows from Figure 4 that the greatest investment is projected to build climate change resilience in agriculture. This tendency implies that among the adaptation strategies, resilience is especially critical in developing African agriculture. In the ecological definition, resilience implies constructing the capability of a system to withstand shocks and to reconstruct and react to change as well as unexpected alteration (e.g. Holling, 1973). Climate change resilience can be construed as the capability of an individual and/or community to vigorously and efficiently respond to shifting the impact-caused environments while functioning at a tolerable level (review in Smit & Wandel (2006)); that is, it is the capacity to endure and recuperate from the negative effects of climate change. The term "adaptation to climate change" has been interpreted as a regulation in natural or anthropogenic systems in response to real or anticipated climatic stimuli or their outcomes, a regulation that eases damage or make use of beneficial chances (IPCC, 2007); whereas, the term "resilience" means the capability over time of a system, community or individual to generate, change and execute various adaptive actions (Rockefeller Foundation, 2009).

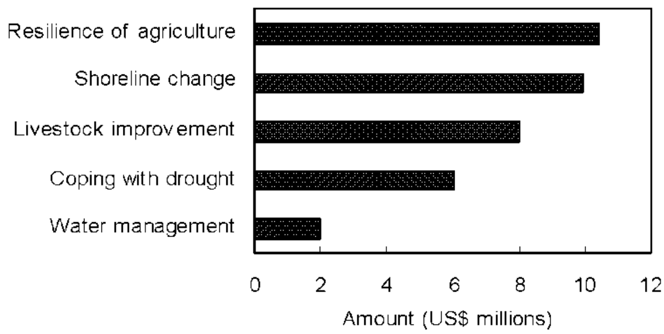

Figure 4. Projects for African adaptation by United Nations Development Programme and Global Environment Facility (adapted from UNDP, 2007)

Considering the above-mentioned multiple actions, the following tools are proposed to create resilience: (i) *flexibility* – with the individual and/or systemic level able to react to shifting and unexpected conditions; (ii) *multi-phased set* – capabilities that facilitate thorough preparation, enduringness and recovery; *redundancy* –an organization, commune or system permits partial malfunction within a system or organization without entire fail; *multi-sectional approaches* – since one sector does not have a monopoly on a specific risk (i.e. comprehending the overlaps), sector gaps are critical; (iii) *plan and prudence* – while it is not possible to prepare for ally probable set of negative effects, the process of planning aims at learning and building skills; (iv) *diversity and decentralization of planning* – a variety of choices has great potential to deal with the specific scenario of negative effects that occurs; *plans for malfunction* – the unforecastability and improbability of climatic risks and responses will finally lead to failure of the system unless it permit to plan disaster recovery (i.e. failure planning).

4.2 Climate-Resilient Crops

The social/organizational tools in section 4.1 seem not to be sufficient by themselves to create resilience. It is predicted that agricultural sector will be injured by intense droughts and/or salinisation of surface water (cf. section 3). Drought is frequently associated with salinity, and the linkage of drought with salinity becomes a serious matter of great concern (Ledford, 2007). Therefore, the targets of climate change adaptation should include developing drought- and salt-tolerant crops for agriculture.

In arid and semi-arid regions, annual plants link a short-term lifecycle with an elevated growth ratio in the wet season to avoid drought, regulating sink/source allocation by increasing roots and decreasing leaves (Rivero et al., 2007). Usually, such plant species have been considered to be stress avoiders by escaping an harsh season as dormant seeds. Nevertheless, botanical response to stress varies from stress avoidance to stress tolerance, the second being expressed more in perennial plants that slowly grow (Chaves et al., 2003). How to maintain desirable internal water and botanical mechanism at low potential of leaf water is the main physiologic system that renders service to keeping good productivity under drought conditions (Blum, 1996). It is reported that the yield of transgenic plants (e.g. tobacco) decreases 12% when watered with 70% less water than normal irrigation (Rivero et al., 2007). It is therefore considered that transgenic technique contributes to improving drought tolerance in crops.

The salt contained in the water causes the plants to use additional energy in absorbing water from the soil and as a consequence leaves the plants with less energy applicable to growth; consequently, leaves become dark, thick and succulent. These leaves show less growth rate than non-stressed plants (review in Kafi & Khan (2007)). The following ways have been suggested to develop salt-tolerant crops (Flowers & Yeo, 1995): to cultivate halophytes as optional crops; to develop specific hybridization to improve the tolerance of present vegetation; to use the deviation already present in known vegetation; to increase deviation within known crops by applying intermittent selection, mutagenesis or tissue culture; and to breed for yield rather than tolerance. Mutagenesis has discovered a lot of salt-sensitive types (Borsani et al., 2002), and this approach is now being widely advocated. Instead of researching salt-tolerant plants, it also seems possible to use moderate or high tolerant crops; for instance, barley, cotton, safflower, sugar beet and wheat.

The approach based on tolerant crops requires the use of slanting floor where seeds are planted on the inclined part below the area of salt concentration; the employment of a diversity of soil control measures such as chemical amendments, deep ploughing, organic manure, surface sanding, tillage, etc.; and the use of proper water supply and allocation, especially keeping away from over-irrigation (cf. Borron, 2006; Kafi & Khan, 2007). Thus, it can be considered that there are possible solutions to the salinity problem.

5. Green Revolution

A preferred approach to agriculture development has been called "green revolution". This term is used to refer to a time from 1960 to 1990 when there was a remarkable movement in agriculture sector in developing countries (cf. FAO, 1997). This revolution generally recommends some basic elements (FAO, 1997): breeding for seed improvement, farm technique, reasonable irrigation and fertilization. It is an agricultural trend in all the world. Excluding fertilizers, the other three elements stated above are associated with the methodology stated in section 4.1. That is, actions for agricultural resilience (section 4.1) are closely linked with the concept of the green revolution. It can be considered that the agricultural sector commonly has a grounding in resilience-based adaptation.

5.1 Modelling

Since the 2SLS model (McKinsey & Evenson, 1999) simulates climate-technology interaction in regional agriculture, it is applicable for finding out whether or not regional climate variations will condition the local trend of investment and agrotechnical adaptation as the unfolds of green revolution. The model structure is simply expressed as:

HYV = f_1(DBLCR, IRR, RES, EXT, EDA, CLIM)

IRR = f_2(IRR_{57}, HYV, EDA, CLIM)

DBLCR = f_3($DBLCR_{57}$, HYV, IRR, EDA, CLIM)

where HYV = the rate of land planted to high yield; IRR = irrigation intensity (ratio of net irrigated zone to net cultivated zone); DBLCR = the extension of multiple-cultivated zone (ratio of gross cultivated zone to net cultivated zone); RES = the stock of public R&D services; EXT = communal extension; EDA = soil-related vector – inclination, soli property, etc; CLIM = climatic vector such as standard temperature, precipitation, etc.; IRR_{57} and $DBLCR_{57}$ = rates of irrigation and multiple-cultivation in 1957, respectively.

Based on this model, the following equations can be derived (McKinsey & Evenson, 1999):

(i) the effects of climate C on the production and diffusion of technology T is expressed as:

$$\frac{dNR}{dC} = \frac{\partial NR}{\partial C} + \frac{\partial NR}{\partial T} \bullet \frac{dT}{dC} \quad (1)$$

where NR = net income

(ii) the influence of technology on climatic effect is expressed as:

$$\frac{d\left(\frac{dNR}{dC}\right)}{dT} \quad (2)$$

(iii) the influence of climate change on technologic effect is expressed as:

$$\frac{d\left(\frac{dNR}{dT}\right)}{dC} \quad (3)$$

5.2 Results

The above-mentioned model structure allows for farmer's adaptation to regional-level climate conditions (and to climatic variations which may take place over a long period from the present to the future). This adaptation embraces investments in farm-level irrigation and drainage as well as patterns in farming works including cropping variations. There is also potential adaptation by the institutions promoting technical progress and infrastructural expansion for farmer communities.

A performed simulation indicates that higher rates of climate change (i.e. temperature, rainfall and so on) would increase the refund to investments in technologic improvement and infrastructural expansion, and increases in the use of up-to-date variations and in the rate of multi-cultivation would mitigate and improve the effects of a temperature increase.

Table 1. Simulation results of 2SLS model: technological change relationships

Effect of a 1% Δ in:	Resultant % Δ in:		
	HYV	DBLCR	IRR
HYV	—	0.311	0.335
DBLCR	0.396	—	0.133
IRR	0.616	0.225	—

Table 1 represents that the amplified adoption of contemporary variations has been a vital driver to the investment in irrigation systems and to the extension of multiple-cultivation (cf. the top row in the Table) at the same time that the adoption of the contemporary variations has responded powerfully to the spread of irrigation system and multiple-cropping (cf. the left column in the Table). The multiplier effects of multiple-cultivation and irrigation system, while positive, have been less argued. On the whole, Table 1 has the backing of the importance of a set of inputs and practices, strengthening both parties, in order to accomplish the Green Revolution.

6. Conclusion

Adaptation is associated with community development, and this association is significant to diminish susceptibility to climate change. Economic progress is important for developing countries to make various improvements such as the public health, income and life quality. It is also essential to raise the ability of developing countries to adapt to the climatic impacts. The African challenges to climatic impacts and the necessity for adaptation are various. A comprehensive approach is therefore considered necessary to achieve these challenges. In Africa, agriculture has an important role from the viewpoints of national economy and employment (section 1), and it is estimated that climate change will affect African agriculture in particular (Figure 3): rainfall, temperature and water accessibility for agricultural uses will be influenced by climate. The African region is damaged by a decrease of crop yields, which influences food security of people that already suffers of undernourishment, and menaces the dependence of food supply on agricultural productivity.

It is considered that resilience-based actions will play a major role in adaptation of African agriculture (Figure 4). As described above in section 5, these actions basically overlap with a part of the concept behind the green revolution (the so-called Green Revolution II): the essence of Green Revolution I (1960s-1990s) was high-yielding plant varieties; in contrast, Green Revolution II calls for an exemplar shift in agricultural strategy to focus on making plants more resilient to global warming rather than on increasing yields. Based on a model simulation presented in this manuscript, there is a potentiality that climate change may affect agronomic progress and its spread, and that agronomic progress and spread may affect the climatic impacts on agricultural productivity (Table 1).

One important task of climate change adaptation lies in understanding the full scope of its implications, and a comprehensive approach is considered necessary to achieve this task (cf. section 1). The concept of Green Revolution II is given as a comprehensive example: the focus of crop research should be reoriented towards adaptation to environmental stress, such as rising temperatures and water scarcity.

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