Addressing Climate Change Cause and Effect on Land Cover and Land Use in Africa

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By

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Abstract

This study investigates the impact of climate change on land-use change and land-cover (LCLUC)-induced greenhouse gas emissions in Africa. In particular, it tests the hypothesis that increasing agricultural productivity can be a land-based climate mitigation strategy to address the issue of LCLUC-induced emissions. The results confirm the well-known fact that climate change will have a devastating impact on Africa's agricultural sector and therefore the welfare of the people. However, the results also clearly demonstrate that technology can be leveraged to improve agricultural productivity, which will not only enhance food production and improve food security but also mitigate greenhouse gas emissions. Specifically, we show that employing agricultural intensification strategies based on lifting total factor productivity can increase agricultural output with less land use, thereby saving millions of hectares of land from being brought into cultivation for staple crop production.

Keywords: *Climate change, Land use, Agricultural intensification, Agricultural productivity*

JEL codes: *Q54, Q24, Q15, C68*

1. Introduction

Africa has been identified as the region most at risk to climate change due to its high dependence on natural resources and rain-fed agriculture.[2] Current climate-related stressors such as drought, floods, rainfall variability, coupled with low adaptive capacity make African countries highly vulnerable to future climate change. The scientific evidence indicates that climate change will have adverse impact on Africa's water resources, marine and forest ecosystems, health systems, infrastructure and energy resources. Climate change will also adversely impact forest and marine ecosystems with adverse implications for the local communities who depend on them for their livelihoods. There will be increased internal migration as people attempt to escape crop failure, water scarcity and sea-level rise. This will put pressure on physical and social infrastructure, provision of which is already inadequate. There will also be an increased risk of violent conflict due to shrinking natural resources.

In addition to the issues mentioned above, there are a number of global forces (or megatrends) currently underway that will compound the challenges African countries face in transforming their economies. These megatrends include demographics, climate change, urbanization and technology and innovation. Demographic trends will double Africa's current population to 2.4 billion by 2050 (UNDESA, 2017), putting pressure on the supply of natural resources such as food, water, energy and ecosystems. By 2050, about half of Africa's population will be under 18 years of age and most of them will be living in cities. There will be pressure on governments to find solutions to the problem of youth unemployment, which is currently at high levels and represents a potential security threat.

Africa's vulnerability to climate change is further exacerbated by other factors such as poverty, governance and institutional challenges, and limited access to capital, including markets, infrastructure and technology. These factors have in turn contributed to Africa's weak adaptive capacity relative to other regions of the world. African women are particularly vulnerable to the impact of climate change because they shoulder an enormous portion of responsibility for subsistence agriculture, the productivity of which is expected to be adversely impacted by climate change and mining of the soil. Many African countries are already under various forms of climate-related stress such as drought, floods, and rainfall variability which, coupled with low adaptive capacity, make them highly vulnerable to future climate change.

Although the issue of global warming from the burning of fossil fuels has been at the centre of mitigation efforts to date, another issue of concern is the contribution of land-cover and land-use change (LCLUC) greenhouse gas (GHG) emissions. The Intergovernmental Panel on Climate Change (IPCC, 2014) notes that around 24% of global GHGs are produced from the land-use sector, second only to the energy sector, while Vermeulen et al. (2012) estimate that 6% to 18% of GHG emissions are due to LCLUC. African agriculture contributes about 15% of global agricultural GHG emissions compared to 13% for Europe and 25% for the Americas (FAO, 2014). While Africa's per capita emissions of GHGs remain the lowest in the world at 3.9 tonnes CO_2e (when LCLUC is included), its future emissions' growth will be rapid on current trends. For example, between 2000 and 2010, agricultural expansion, primarily of smallholder farms, accounted for approximately 70% of forest loss in the region (African Progress Panel, 2015).

Another significant driver of deforestation, and a growing source of emissions, is the high dependence on traditional biomass to meet household thermal energy needs.[3] Therefore, although the region is facing massive development challenges such as poverty and inadequate education, health care and energy access, it must play its role under the Paris Agreement to avoid large-scale increases in GHG emissions.

Africa's crop yield per unit land area lags other regions of the world due mainly to the slow pace of technology diffusion across the continent. Although Africa still has more cultivable land compared to other continents, large areas of land are being lost annually to urbanization, other non-agricultural land uses, salination, desertification and soil erosion (Godfrey et al., 2010). Therefore, the prospects of bringing new land into agricultural production is looking less likely.

One of the ways of raising crop productivity is to raise the yield per crop per hectare by employing agricultural intensification strategies on farmlands. The gap between African crop yields and the rest of the world is currently about 41% (Tian and Yu, 2019). Therefore, there is still great potential to increase productivity in Africa. Agricultural intensification can also help mitigate deforestation by reducing the clearing of additional land for farming, which will help reduce LCLUC-induced CO_2 emissions.

The foregoing discussion throws up a complex problem for policy makers in their efforts to address GHG emissions. Land use affects climate change with GHG emissions triggered by deforestation. Climate change will also affect future land cover and land use, resulting in climate-induced negative impacts on agricultural productivity. Thus, a key challenge for sustainability is how to feed a growing population while preserving forest ecosystems and their services. In this regard, the overall aim of this research project is to generate recommendations based on the evidence that would help to mitigate LCLUC emissions and at the same time offset the adverse impacts of climate-induced crop productivity changes on agricultural production.

The objectives of this study are therefore twofold. First, we investigate the impact of climate change on LCLUC-induced emissions in Africa. Second, we test the hypothesis that increasing agricultural productivity can be a land-based mitigation strategy for LCLUC-induced emissions. The overall goal of the research project is to initially document the impact of climate change on LCLUC-induced emissions at a highly aggregated level as the first stage. This will then be followed by further studies at the regional and country levels to identify specific policies targeted at individual countries and ecological zones.

The remainder of the paper is organized as follows. Section 2 sets the stage by providing a broad brush review of the literature on agriculture production and climate change, land use change and CO_2 emissions. Section 3 discusses the methodology used, the data and the simulation experiments undertaken. The results are presented and discussed in Section 4, while Section 5 concludes.

2. Relationship between climate, land use and emissions

The nature of land use in any particular location is strongly influenced by climate. In particular, the agriculture and forestry sectors are very vulnerable to climate change, which will alter the relative productivity of lands. Land use affects climate change in three ways. First, land use patterns influence GHG emissions; second, land use is important in assessing the impact of climate change; and third, land use is necessary for the reduction of GHG emissions (Hertel et al., 2008). With approximately 80% of the crop and pasture lands expanding by replacing forests, particularly in the tropics (Gibbs et al., 2010), land-cover change has become a significant source of CO_2 emissions (Vermeulen et al., 2012). In the period 1750 to 2011, forestry and other land use accounted for about a third of anthropogenic CO_2 emissions, while they accounted for about 12% of emissions from 2000 to 2009 (IPCC, 2014).

A number of empirical studies indicate that regional agricultural production could be significantly affected by climate change, especially in the poorer regions of the world. For example, Hertel et al. (2010), Laborde (2011) and Knox et al. (2012) projected the impact of climate change on agricultural production in various regions of the world and found significant declines in crop yields by the 2050s. More recently, Bandara and Cai (2014) and Cai et al. (2016) have analyzed the impact of climate-induced productivity changes on food production and prices in South Asian countries and found significant adverse effects. It is expected that these crop productivity changes will in turn lead to land-use changes. Recent empirical studies suggest that land-based mitigation could represent a cost-effective portfolio of mitigation strategies for long-term climate stabilization (Hertel et al., 2008; Ahammad et al., 2012).

World agriculture shows a distinct transition regarding the contribution of extensive (cropland expansion) and intensive (crop intensification) margins to total agricultural production. Before the beginning of the 20th century, production increases in agriculture had been made mainly through the extensive margin, that is by bringing additional land into production rather than increasing production on existing land. However, this drastically changed by the end of the century as almost all improvements were coming through agricultural intensification (Ruttan, 2002). From an empirical point of view, however, the relationship between agricultural intensification and land saving or deforestation is mixed and not clear-cut. There are two conflicting views on this relationship. One is the Borlaug Hypothesis (Borlaug, 2002) in which agricultural innovation leads to land saving (i.e. not using additional land), and the other is the

Jevons Paradox, which hypothesizes that such changes lead to increased land use and associated emissions (Hertel, 2012).

Evidence for the Borlaug Hypothesis is found in some studies in which a positive correlation between agricultural intensification and land saving has been reported (e.g., Stevenson et al., 2013). Nevertheless, in other studies, agricultural intensification and yield increase have led to the Jevons Paradox causing deforestation as productivity gains make agricultural activity more profitable and thus more attractive (Villoria et al., 2013). It has also been recognized that factors such as governance (Ceddia et al., 2014), the nature of innovation (global, regional or farm level), supply elasticity of land, demand elasticity of agricultural products, and emission efficiencies determine the sign of the relationship between agricultural productivity and land saving (Hertel, 2012).

3. Methodology

Two types of economic models have been used to analyze issues related to land use. They are Partial Equilibrium (PE) or econometric models and applied general equilibrium models such as Computable General Equilibrium (CGE) models. PE models assume profit maximization behaviour under risk aversion in land use decisions. They also incorporate both the response of production and consumption to prices, and also the adjustments of these prices to attain global equilibrium between demand and supply for selected commodities. The ability to capture price dynamics in the land-use sector allows detailed spatial and land management characteristics to be represented in these models. However, PE models tend to ignore the rest of the economy (Hertel et al., 2008), which is a disadvantage in land use modelling as there are many economy-wide indirect effects. In contrast, CGE models consider all the direct and indirect effects of land use and can generate useful insights in both ex-ante and ex-post scenarios.

CGE models have been used over the past two decades to analyze the impact of climate change on land use. The Future Agricultural Resource Model (FARM) was the first CGE model used to estimate the potential effects of global climate change on the availability and productivity of suitable agricultural land and the extent to which they expand (or contract) in response to climate change (Darwin et al., 1995). However, land use is disaggregated by physical characteristics in the FARM, and thus land endowment by category is an aggregate taken from a spatially explicit bioclimatic model. Although the changes in demand for land use are captured, they are not derived from optimal behaviour. It is thus argued that the FARM model brings biophysical realism into the economic model, but not economic realism into the biophysical model (Hertel et al., 2008).

The GTAPE-L model (L refers to land and E refers to energy) is an extension of the standard GTAP model. It also extends the work of Darwin et al. (1995) with explicit tracking of inter-sectoral land transition and estimation of sectoral net emissions due to land-use change (Burniaux and Lee, 2003). However, the input data was rudimentary. The latest model, in contrast, the GTAP-AEZ model overcomes those issues associated with the earlier work by incorporating a more extensive land-use database, and a more sophisticated representation of land-based emissions and forest carbon sequestration (Hertel et al., 2008).

In this study, we use the GTAP-AEZ model, which facilitates more comprehensive analyses of the trade-offs due to climate change, alternative land use, and land-based mitigation strategies in an economy-wide framework. It also considers land rent effects and the impacts on land use via factor market effects. Previous versions of the GTAP AEZ model have been used extensively to analyze issues related to climate change, agricultural land use and GHG mitigation analysis (e.g. Byerlee et al., 2014; Villoria et al., 2013). The GTAP AEZ model is discussed in further detail below.

The following subsections discuss the GTAP-AEZ model and the simulation strategies used in this study.

The GTAP-AEZ model

The GTAP-AEZ model relies on the standard neoclassical assumption whereby consumers maximize utility. There is a representative regional household whose expenditures are governed by an aggregate Cobb-Douglas utility function that allocates constant budget shares of the expenditure across three types of final demand: private, government, and savings. Private household preferences are represented using the non-homothetic constant difference elasticity functional form. Firms are assumed to maximize profits subject to a nested constant elasticity of substitution production function, which combines primary factors and intermediate inputs to produce final goods. Firms pay wages/rental rates to the household in return for the employment of factor endowments (land, labour, capital and natural resources). Firms sell their output to the other firms (as intermediate inputs), to private households, government, and to the global market. They export tradable commodities and import intermediate inputs from the other regions. Following the Armington assumption (Armington, 1969), goods are differentiated by their country of origin and thus the model tracks bilateral trade flows (Hertel, 1997).

The land-use database disaggregates land endowment and the three land-use activities (cropland, grazing land, and forest) into 18 global AEZs based on six (6) different lengths of growing periods (6 x 60-day intervals), and three climatic zones (tropical, temperate and boreal) (Monfreda et al., 2009). Ideally, there should be a distinct production function for each AEZ/crop combination in the model, but this results in a massive proliferation of sectors in the model competing in the product market. Thus, while preserving its economic content, the model is simplified to have a single national production function with multiple AEZ inputs, and the elasticity of substitution within a national land aggregate and across AEZs within that production function is set to a high value of 20.

Land mobility within each AEZ is modelled through a nested constant elasticity of transformation (CET) frontier, whereby a two-tier structure determines the optimal behaviour. That is, first, the rent-maximizing landowner decides the allocation of land among the three land-use activities based on the relative returns to land, and secondly, he decides the allocation of cropland between different crops according to the relative returns in the crop sectors. Following Ahmed et al. (2008), we use the CET parameter among three land-use activities ($\Omega_{)}$) of -0.5 to reflect the flexibility of land conversion over the next 25 years of time horizon considered in this study. Also, the parameter value for the elasticity of transformation of cropland among different crops (Ω_2) is set to one, reflecting the higher flexibility of this conversion than (Ω_1). Based on the historical patterns of bilateral trade, and the specified Armington assumption, the model determines the countries in which agricultural area expansion or contraction takes place.

Aggregate database and shocks

For the analysis, we used the land-use augmented version of the GTAP 8. We combined the original 113 GTAP regions into 15 regions, including sub-Saharan Africa. North Africa is aggregated with the Middle East given the similarities in their AEZs. Furthermore, the original 57 GTAP commodity sectors were aggregated into 14 sectors to facilitate the analysis.

To simulate climate-induced productivity shocks, we took estimates from Hertel et al. (2010) in preference to others such as Knox et al. (2012) and Laborde (2011) because it has a wider coverage of crops. We considered two crop productivity scenarios: (1) the 'most likely' or 'central case', which we refer to as the 'medium crop productivity scenario'; and (2) an 'extreme case' which we refer to as the 'low crop productivity scenario'. The latter assumes a world with rapid temperature change, a high sensitivity of crops to warming, and a CO_2 fertilization effect at the lower end of published estimates. The assumed climate-induced output augmented technical change reflected in the percentage of crop productivity changes in major crop sectors are shown in Table 1 below. These climate-induced productivity shocks are used to simulate changes for all the regions in the world to compare with the results for Africa, particularly for changes in land use and the induced CO_2 emissions resulting from that. More detailed results are also analyzed for Africa, given the focus of the paper.

To investigate the potential of agricultural intensification for mitigating deforestation and LCLUC-induced CO_2 emissions, we first estimated yield gaps for the selected major crops, namely, rice and maize, millet and sorghum. For the purposes of the modelling, maize, millet and sorghum are aggregated under 'other cereal grains'. The average yield gaps for rice and coarse grains were taken from AfricaRice (2012) and Tian and Yu (2019), respectively. Next, we used statistics from the Food and Agricultural Organization (FAOSTAT) and the Global Agro-Ecological Zones (GAEZ v3.0) database to calculate the linear trends of actual and potential yields for the selected crops. We then calculated the total factor productivity growth (TFP) required to close the yield gap by 50% for sub-Saharan Africa. Finally, we used the productivity shocks to analyse the potential of increased TFP as a land-based mitigation strategy for LCLUC-induced CO_2 emissions.

Table 1: Productivity shocks considered

Region	Low crop productivity scenario						High crop productivity scenario					
	Rice	Wheat	Coarse grains	Oil seeds	Vegetable, fruit, nuts	Other crops	Rice	Wheat	Coarse grains	Oil seeds	Vegetable, fruit, nuts	Other crops
Brazil	-10	-10	-17	-5	-10	-10	-3	-3	-10	2	-3	--3
Canada	-10	-5	-17	0	-10	-10	-3	7	-10	12	2	2
China	-12	-10	-22	-12	-15	-15	0	2	-10	0	-8	-8
EU 27	-5	-5	-17	-5	-5	-5	7	7	-5	7	7	7
Indonesia	0	0	7	0	0	0	7	7	0	7	7	7
India	-15	-10	-17	-10	-10	-10	-5	-3	-10	-3	-3	-10
USA	-10	-10	-32	-10	-10	-10	-3	2	-15	2	2	2
Rest of East Asia	5	5	-2	5	5	5	12	12	5	12	12	12
Rest of Latin America	-10	-10	-17	-10	-10	-10	-3	-3	-10	-3	3	3
Rest of the World	-5	-5	-17	-7.5	-5	-5	7	7	-5	4.5	7	7
Rest of South Asia	-15	-10	-17	-10	-10	-10	-5	-3	-10	-3	-3	-3
Rest of Southeast Asia	-10	-10	-17	-10	-10	-10	-3	-3	-10	-3	-3	-3
North Africa & Middle East	-5	-5	-12	-5	-5	-5	2	2	-5	2	2	2
Sub-Saharan Africa	-15	-15	-22	-15	-15	-15	-3	-3	-10	-3	-3	-3

Source: Modified from Hertel el al., (2010).

4. Results

Impact of climate change on agriculture and land use

Low crop productivity scenario

The climate-induced crop productivity shocks under the low and medium scenarios for sub-Saharan Africa were applied in this simulation experiment. The imposition of these shocks allows us to track the changes in production, prices, land cover, and LCLUC-induced CO_2 emissions in the new equilibrium. Under the low crop productivity scenario, there are production declines across all crops for sub-Saharan Africa in 2030 (Figure 1A).

Figure 1: Impact of climate-induced low crop productivity on agriculture and the environment in Africa

Source: GTAP model simulations

The declines range from -5% (coarse grains) to -19% (wheat). The production declines are much less for North Africa and the Middle East and some crops such as coarse grains and other crops actually see an increase in output. The output reductions lead to increase in local prices by more than 50% across all crop types, with prices for coarse grains in sub-Saharan Africa rising by as much as 86% (see Figure 1B). Prices also rise for North Africa and the Middle East but to a lesser extent. The reduction in output means that domestic food production must be supplemented by imports.

The higher agricultural prices make production more profitable, causing factor inputs to be drawn away from other activities. Therefore, we observe an expansion of cropland by more than 5% in both sub-Saharan Africa and North Africa and the Middle East at the expense of shrinking forest and pasture lands (see Figure 1C), resulting in deforestation across the continent. The expansion of croplands in Africa is driven entirely by increases in the harvested area of rice, wheat and coarse grains. At the global level, the low crop productivity scenario causes substantial increases of cropland use of 62.3 Mha and this is compensated entirely from pasture lands, enabling some reforestation of 2.5 Mha. Figure 1D shows that because of the cropland expansion and regional deforestation, CO_2 emissions increase in sub-Saharan Africa by 766 million t CO_2, while they increase by 151 million t CO_2 for North Africa and the Middle East. There are also increases in CO_2 emissions from pastures. However, the emissions are offset to some degree by reductions of 236 and 89 million t CO_2 from croplands for sub-Saharan Africa and North Africa and the Middle East, respectively

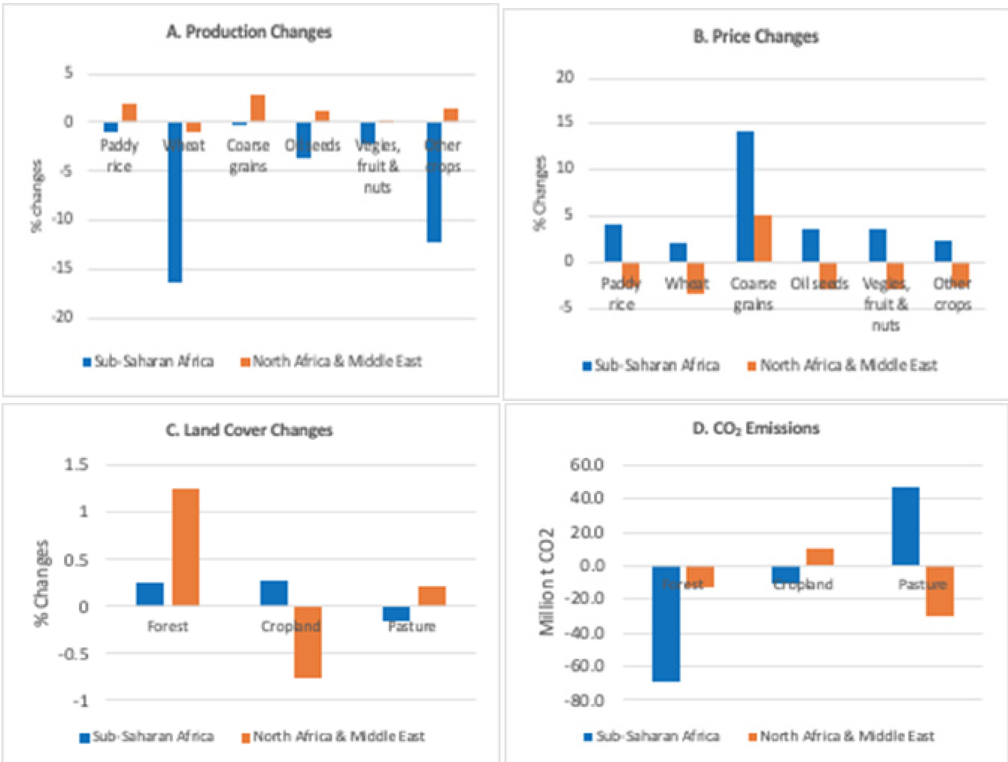
Medium crop productivity scenario

Under the climate-induced medium crop productivity scenario, we again observe declines across all the crop types in sub-Saharan Africa (Figure 2A). However, for crops such as paddy rice, coarse grains, oil seeds and vegetables, fruit and nuts, the falls are much less than in the low crop productivity scenario. For crops such as wheat and other crops, there is not much difference in the declines under the two scenarios. For North Africa and the Middle East, production of all crop types except wheat increase under the medium crop productivity scenario (see Figure 2A). This can be attributed to the superior agricultural systems in this region compared to sub-Saharan Africa.

Given the different pattern of production changes in the two regions, we observe corresponding changes in the pattern of price changes. Prices for all crop types increase in sub-Saharan Africa, while we observe price falls in North Africa and the Middle East due to increase in crop production. The price of coarse grains increases the most in both regions while the production loss in paddy rice is moderate, with the second most price increase in both regions (see Figure 2B).

In terms of land cover loss, forest land and cropland increase moderately under the medium crop productivity scenario in sub-Saharan Africa, while there is a small loss in pastures. Forest cover in North Africa and the Middle East increases by more than 1%. However, this is offset by a decline in cropland. Corresponding to the increase in land cover for forests and cropland in sub-Saharan Africa, we observe a decline in CO_2 emissions, although this is offset by a rise in emissions from pastures corresponding to the land cover loss. A similar pattern is observed for North Africa and the Middle East.

Figure 2: Impacts of climate-induced medium crop productivity on agriculture and the environment in Africa



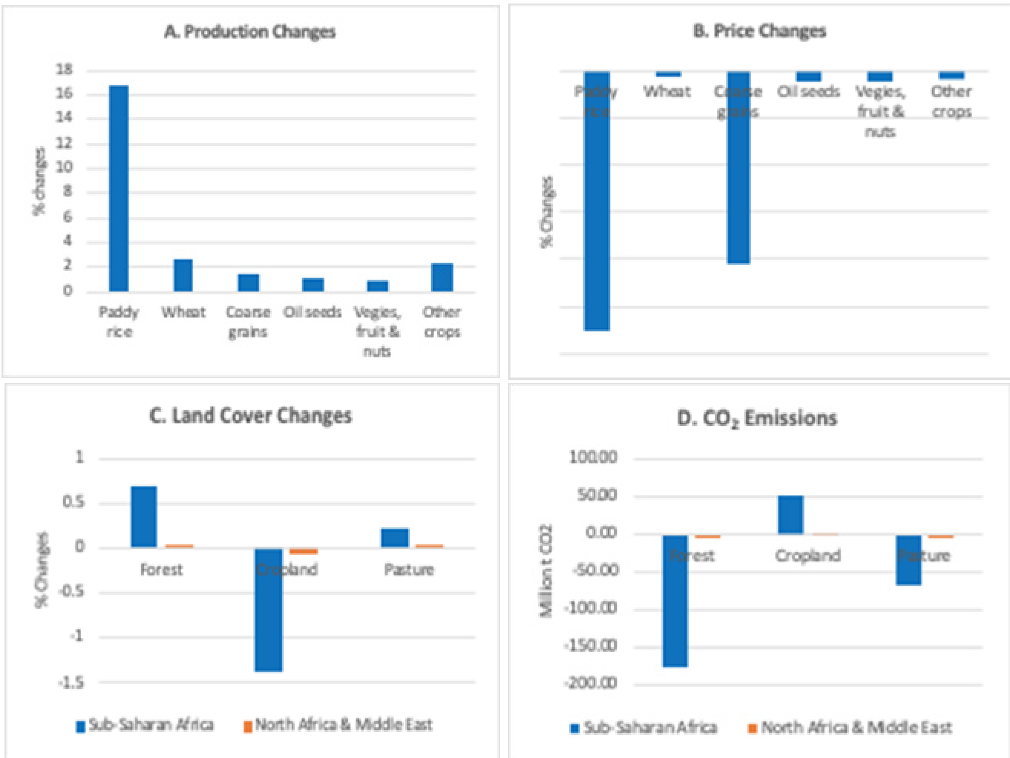
Source: GTAP model simulations

Mitigating the effects through improvements in productivity growth

The last policy experiment examines the possibility of mitigating the adverse impacts of climate change by increasing total factor productivity (TFP) to close the yield gap for two major crop types—paddy rice and coarse grains. Recall that productivity improvement is applied only to agriculture in sub-Saharan Africa. We track the effect of the policy on production, prices, land-use changes, LCLUC-induced emissions and trade. Starting with production, with the productivity improvement, there are production increases for all crop types. Paddy rice, wheat and coarse grain production increased by 17%, 3% and 2%, respectively (Figure 3A). In line with this trend, we observe reductions of 28%, 1% and 21% in the respective prices (Figure 3B).

The productivity improvement leads to increased land cover from forests and pastures, while landcover from crops decline (Figure 3C). The forestry reversion and other land-use changes associated with TFP growth reduces LCLUC-induced CO_2 emissions by 246 million t CO_2 in sub-Saharan Africa (Figure 3D).

Figure 3: Impacts of productivity growth on agriculture and the environment in Sub- Saharan Africa



Source: GTAP model simulations

This scenario shows that with technological progress, imports of key crops such as rice and coarse grains decline, while exports increase. For example, sub-Saharan Africa's exports of paddy rice and coarse grains increase by as much as 178% and 28%, respectively, compared to the baseline scenario (Figure 3E). This leads to the region moving from being a net food importer to a net food exporter in the counterfactual scenario, contributing to a sizeable trade surplus of US$ 726 million. The increased productivity of primary factors and intermediate inputs also enables a saving of 16.7 Mha of cropland from being cultivated, thereby increasing landcover and reducing CO_2 emissions.

5. Conclusions

The issue of global warming caused by the burning of fossil fuels has been the focus of climate mitigation efforts to date. However, the issue of growing emissions from LCLUC greenhouse gas emissions is one that needs to be addressed. Around a quarter of global GHGs are produced from the land-use sector, second only to the energy sector. In Africa, the data shows that agricultural expansion accounts for a major share of forest loss. That, together with other factors such as urbanization, other land use, salinization and desertification are major drivers of GHG emissions on the continent. It is therefore important for policy makers to find ways to feed a growing population while preserving forest ecosystems and their services.

In line with these concerns, this study sets out to investigate the impact of climate change on land- use change and LCLUC-induced emissions in Africa and to test the hypothesis that increasing agricultural productivity can be a land-based climate mitigation strategy for LCLUC-induced emissions. The results confirm the well-known fact that climate change will have a devastating impact on Africa's agricultural sector and therefore the welfare of the people. However, the results also show that technology can be leveraged to improve agricultural productivity, which will not only enhance food production but also mitigate emissions. Specifically, we showed that using agricultural intensification strategies based on lifting total factor productivity can increase agricultural output with less land use, thereby saving millions of hectares of land from being brought into cultivation for staple crop production. The results also support the Borlaug hypothesis, which argues that land can be saved in response to agricultural intensification through productivity growth at both regional and global levels.

In conclusion, the limitations of the study must be acknowledged. These mostly pertain to the assumptions of the model used. First, the GTAP-AEZ is a comparative static model that assumes a single national production function for each agricultural commodity with multiple agro-ecological zones (AEZ) inputs, where they are combined using a single elasticity of substitution. Second, the model deals with land heterogeneity using a simple Constant Elasticity of Transformation function. Thus, improvements to address the model's limitations could be considered in future research to provide more robust results. In light of the critique provided by Charlton and Stiglitz (2005) on estimates of CGE model impacts, it is important to keep in perspective that these are not forecasts but rather indications of the direction and perhaps the intensity of the projected impacts. Another possible avenue for future research is to consider and compare other GHG emission mitigation policies such as taxes and zoning incentives, and a combination of these policies or an optimum mix of policies to deliver efficient or desired targets.

Notes

1. African Centre for Economic Transformation, Accra, Ghana and University of Queensland Brisbane, Australia

2. Just about 4% of the total area in production in sub-Saharan Africa is under irrigation, compared with 39% in South Asia and 29% in East Asia (World Bank, 2007).

3. It is estimated that nearly 80% of Africa's energy demand relies on traditional biomass (IEA, 2014).

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Appendix

Table A1: Regional and sectoral aggregation

Aggregated Regions	Countries Included	Aggregated Sectors	Commodities Included
1. Brazil		1. Paddy rice	
2. Canada		2. Wheat	
3. India		3. Cereal grains nec[1]	
4. USA		4. Oil seeds	
5. Indonesia		5. Vegetables, fruit, nuts	
6. China	China, Hong Kong, Taiwan	6. Other crops	Sugar cane, sugar beet, Plant-based fibers, Crops nec.
7. Rest of South Asia	Bangladesh, Sri Lanka, Pakistan, Rest of South Asia.	7. Forests	Forestry
8. Middle East and North Africa	Egypt, Iran, Morocco, Tunisia, Turkey, Rest of North Africa, Rest of Western Asia.	8. Livestock	Bovine cattle, sheep and goats, horses, Raw milk, Wool, silk-worm cocoons.
9. Rest of East Asia	Korea Republic of Rest of East Asia.	9. Animal products	Animal products nec
10. Rest of Southeast Asia	Cambodia, Lao People's Democratic Republic, Myanmar, Philippines, Singapore, Thailand, Viet Nam, Rest of Southeast Asia.	10. Processed agriculture	Bovine meat products, Meat products nec, Dairy products, Processed rice, Sugar, Food products nec, Beverages and tobacco products.
11. Sub-Saharan Africa	Botswana, Ethiopia, Madagascar, Mozambique, Mauritius, Malawi, Nigeria, Senegal, Tanzania United Republic of, Uganda, South Central Africa, Central Africa, Rest of Eastern Africa, Rest of South African Customs, Rest of Western Africa, South Africa, Zambia, Zimbabwe	11. Vegetable oils and fats	

continued next page

Table A1 Continued

Aggregated Regions	Countries Included	Aggregated Sectors	Commodities Included
12. EU 27	Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Germany, Denmark, Spain, Estonia, Finland, France, United Kingdom, Greece, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, Malta, Netherland, Poland, Portugal, Romania, Slovakia, Slovenia, Sweden.	12. Manufacturing	
13. Rest of Latin America	Argentina, Bolivia, Chile, Colombia, Costa Rica, Ecuador, Guatemala, Mexico, Nicaragua, Panama, Peru, Paraguay, Uruguay, Venezuela, Rest of Central America, Caribbean, Rest of North America, Rest of South America	13. Chemical, rubber, plastic products	Fishing, Coal, Oil, Gas, Minerals nec, Textiles, Wearing apparel, Leather products, Wood products, Paper products, publishing, Petroleum, coal products, Mineral products nec, Ferrous metals, Metals nec, Metal products, Motor vehicles and parts, Transport equipment nec, Electronic equipment, Machinery and equipment nec, Manufactures nec.
14. Rest of the World	All the other countries not mentioned above	14. Services	Electricity, Gas manufacture, distribution, Water, Construction, Trade, Transport nec, Water transport, Air transport, Communication, Financial services nec, Insurance, Business services nec, Recreational and other services, Public administration, Defense, Education, Health, Dwellings.

Source: Author's aggregation using GTAP database Version 8.

Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

The mission rests on two basic premises: that development is more likely to occur where there is sustained sound management of the economy, and that such management is more likely to happen where there is an active, well-informed group of locally based professional economists to conduct policy-relevant research.

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