The economic effects of soil erosion in Africa: a 2050 analysis

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Abstract

This paper investigates the economic impacts of soil erosion on the African continent in 2050. Soil erosion rates are converted into land productivity losses and fed the MAGNET CGE model.

Preliminary results suggest that declining productivity in agriculture arising from the deterioration of the land factor will have a negative and unevenly distributed economic impact on the African economies. The most affected countries will be Nigeria and those located in the central-eastern region.

Keywords: soil erosion, land productivity loss, Africa, computable general equilibrium, agriculture, food security.

JEL codes:

1. Introduction

Soil degradation is a serious process that is threatening the soil resources and thus is affecting economic development, particularly agricultural production and associated food and nutrition security, provision of ecosystem services and increasing poverty. Among various land degradation processes, soil erosion is recognized as a major environmental problem causing a loss of topsoil and nutrients, reduced soil fertility (Zhao et al., 2013) and, as a consequence, reduced crop yields (Telles et al., 2011). This is of particular concern in many developing countries, where soil degradation may exacerbate other effects of climate change on land productivity (e.g., water scarcity, hot waves, drought, etc.). At global scale, the FAO has recognized the importance of the issue and in May 2015 launched with its Global Soil Partnership a new programme to reduce soil degradation for greater food and nutrition security in Africa[1].

Africa's soils are under threat as 40% are under degradation, especially due to soil erosion, soil nutrient depletion, soil organic matter decline, and soil biodiversity loss. Soil erosion in Sub-Saharan Africa is one of the root causes of stagnating or declining agricultural productivity.

The latest estimates of soil erosion rates confirm the concerning picture for Africa. Borrelli et al. (2017) find that the highest soil erosion rates (which imply higher land productivity losses) occur, among other, in several African countries like Congo, Liberia, Democratic Republic of Congo, Ivory Coast, Malawi and Ethiopia. By converting these estimates into land productivity losses, which fed the MAGNET global CGE model (Woltjer and Kuiper, 2014), Sartori et al. (2019) found that some West African (Cameroon, Cote d'Ivoire, Ghana and Nigeria) and East African countries (Ethiopia, Kenya, Madagascar and Rwanda) suffered substantial losses in horticultural and cereals production. A later study of Borrelli et al. (2020) estimates future soil erosion by water at the year 2070 under different climate-economic scenarios. They find that, on average, land productivity decreases by about 3% at the African continental level.

Based on Borrelli et al. (2020) estimates, Sartori et al. (2021) conducted a second similar economic analysis at the global level with the same multiregional CGE model -MAGNET-). They find that, on average, future crop and GDP losses in the African continent amount to one third and half of total losses. Their results clearly show that, in the long-term, Africa is expected to be one of the most affected continent by soil erosion.

Thus, the purpose of this paper is digging further into the results obtained for the African continent, to learn country-level impacts, disentangle the main drivers and discuss policy measures to mitigate the negative impacts. The analysis will apply the same pioneer approach as described in Sartori et al. (2019)), where country-level estimates of land productivity losses (Borrelli et al., 2020) feed the MAGNET CGE model. The latter will be tailored to the African continent, setting up a regional

[1] African Soil Partnership, https://www.fao.org/global-soil-partnership/regional-partnerships/africa/en/).

disaggregation with the highest number of single African countries/regions. For each single region considered, the study will show the 2050 impact of future soil erosion on national income, crop production, land demand and food prices, as well as the effect on the most relevant SDG, food security and environmental indicators.

This study brings an important contribution to the soil erosion economic literature, which lacks of regional studies that capture the resulting 'second-round' effects of structural economic change that arise owing to shifts in primary resources. To the best of our knowledge, there is no study that fully captures these long-term structural change due to *future* soil erosion, with a closer look at the African continent.

2. Future global soil erosion rates and land productivity losses

The estimates of soil erosion rates computed by Borrelli et al. (2020) are available for some combinations of the Shared Socioeconomic Pathway and Representative Concentration Pathway (SSP-RCP) scenarios, at the year 2070. SSPs include a storyline or narrative, which describes plausible alternative changes in aspects of society such as demographic, economic, technological, social, governance and environmental factors (Kriegler et al., 2012; KC and Lutz, 2014; O'Neill et al., 2017). RCPs describe instead possible greenhouse gas concentration trajectories, consistent with certain socio-economic assumptions, which determines the concentration of GHG emissions in the atmosphere (van Vuuren et al., 2011). In this study, we use the soil erosion rates estimated under the "Middle of the road" (RCP4.5-SSP2) scenario, characterized by social, economics, and technological trends that do not significantly shift from historical patterns. By applying the same methodology as in Sartori et al. (2019), the 2070 soil erosion rates are first converted into land productivity losses, and then linearly scaled down to the year 2050 (Table 1).

Table 1. Regional land productivity losses at the year 2050.

Regions	***RCP45 - SSP2***	***Regions***	***RCP45 - SSP2***	***Regions***	***RCP45 - SSP2***
Egypt	0.0	SouthCenAf	-5.1	RestEastAf	-0.6
Morocco	-2.0	Ethiopia	-5.6	Botswana	-0.4
Tunisia	-0.9	Kenya	-4.5	Namibia	-1.3
RestNorthAf	-1.2	Madag	-4.9	South Africa	-3.1
BkFaso	-0.5	Malawi	-5.6	RestSAC	-6.6
Camerooon	-3.7	Maur	-7.5	*EU27*	*-0.8*
CIvoire	-5.5	Mozam	-3.8	*UK*	*-1.5*
Ghana	-4.7	Rwanda	-6.9	*RestEurope*	*-0.2*
Nigeria	-2.5	Tanzania	-3.9	*Americas*	*-3.3*
Senegal	-0.1	Uganda	-4.4	*Asia*	*-2.7*
RestWestAfr	-1.3	Zambia	-3.6	*Middle_east*	*-1.3*
CentAf	-5.1	Zimbabwe	-4.6	*ROW*	*-0.3*

Source: Borrelli et al. (2020). Own elaboration.

3. Measuring the long-term economic consequences of soil erosion in Africa

3.1 The CGE Model, database and scenario

Neoclassical multi-region CGE models enumerate the theoretical economic tenets of constrained optimisation, to govern the behaviour of agents (i.e., households, producers, government, investors) across the global economy. The behavioural equations are supported by market clearing equations and accounting identity conventions to ensure a stable equilibrium within the closed system of the model.

To underpin the model framework, a 'benchmark' equilibrium year of data representing a balanced system of national economic accounts, gross bilateral trade flows and protection and international transport margins is required. To ensure the model replicates the equilibrium conditions of the benchmark year, the mathematical parameters of the behavioural equations are 'calibrated' to the database. Ensuring that the number of endogenous variables and model equations are equal (closure), powerful computer algorithms are employed to reach an 'equilibrium' solution. More specifically, in response to a policy or structural shock, the economic system moves to a new 'counterfactual' solution characterised by a unique set of prices such that demand matches supply in 'n' markets; income, output and expenditure flows are equal, and the balance of payments between the current and capital accounts nets to zero. Comparing the counterfactual with the benchmark gives an indication of the marginal impact of the shock on market indicators (i.e., typically in terms of prices, outputs, trade flows and real incomes).

In this study, a state-of-the-art recursive dynamic, multi-region, multi-sector neoclassical CGE model, known as the Modular Applied GeNeral Equilibrium Tool (MAGNET) (Woltjer and Kuiper, 2014), is used. Based on the GTAP CGE model (Corong et al., 2017), a key advantage of MAGNET is its modular structure that allows the user to easily switch on/off non-standard modelling extensions which are pertinent to the research question at hand. Given this flexibility, the model has been used in numerous contexts including land-use change (e.g., Schmitz et al., 2014); EU domestic support (e.g., Boulanger and Philippidis, 2015); biofuels and bioeconomy (e.g., Smeets et al., 2014; Philippidis et al., 2018a); food security (Rutten et al., 2013), climate change (van Meijl et al., 2018) and international trade (Philippidis et al., 2018b). In common with the GTAP model, MAGNET is calibrated to the GTAP database (Aguiar et al., 2019), which in this study employs version 10 with a benchmark year of 2014. The GTAP data encompasses 141 regions and countries, 65 tradable sectors and 8 factors of production (including agricultural land).

An important modelling advance over the standard GTAP model is that MAGNET explicitly characterises the rigidity in agricultural factor markets, both in terms of land transfer between different agricultural activities; and in the labour and capital markets to characterise the wage and rent differentials that exist between agricultural and non-agricultural labour and capital markets. As a result, agricultural sector supply responsiveness in MAGNET is relatively inelastic compared with GTAP. In addition, in contrast with the assumption of fixed agricultural land supply in GTAP, the sustainability of land availability is measured more precisely in MAGNET with biophysical data on available agricultural land areas. More specifically, a regional asymptotic endogenous agricultural land supply function signals available land areas corresponding to changes in the real rental rate of land (Eickhout et al. 2009). The potential for bringing additional land into agricultural production is limited to the maximum potentially available land, estimated by the IMAGE land management model (van Meijl et al., 2006; Doelman et al., 2018). The default IMAGE asymptote is defined as the total land available for agriculture, which excludes areas with prohibitively high land conversion costs (mainly ice, desert and wetlands), urban and non-productive protected areas (Woltjer and Kuiper, 2014).

To assess the marginal impact of soil erosion, a “baseline” scenario is perturbed with the regional land productivity losses reported in Table 1. The exogenous shocks are applied to the land productivity parameters of the production function, and are assumed uniform for all cropping activities within the same country. The difference between this counterfactual and the baseline data gives a marginal estimate of the resulting market impacts of soil erosion.

In the baseline scenarios, the regional economies are projected to the year 2050, following exogenous forecasts of some socio-economic variables consistent with the narrative of the RCP4.5-SSP2 scenario. These projections are obtained from Fricko et al. (2017) and from the IMAGE model (Doelman et al. 2018). They include population, Gross Domestic Product (GDP) and endowment (labour, capital stock and natural resources) growth rates, region specific technological change and improvements in land technology. The latter increases the productivity of land over time and may be particularly relevant when simulating a productivity shock to land of opposite sign, as in the case of soil erosion. For this reason, the baseline scenario SSP2 is simulated with (SSP2-A) and without (SSP2-NA) the assumption on land technology improvements.

The 141 regions of version 10 of the GTAP database are aggregated into 36 regions, of which 29 are African countries and regions (Figure 1 and Table A1 of the Appendix).

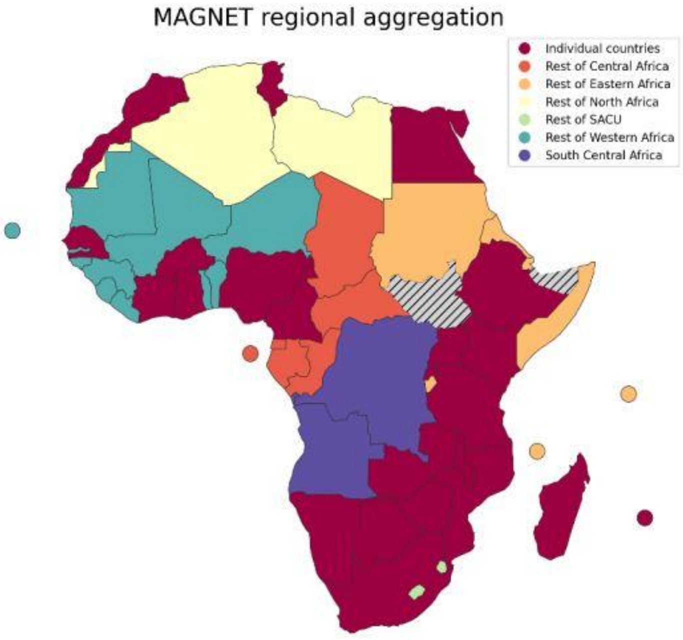

Figure 1. Regional aggregation of the African continent. Source: Simola et al. (2021).

The sector disaggregation includes all GTAP irrigated and non-irrigated agricultural cropping activities (rice, wheat, other cereals, horticulture, oilseeds, raw sugar, plant-based fibers and other crops), all non-arable and food processing activities, fertilizers, energy and natural resources. Non-food manufacturing and non-food services are aggregated into three macro-sectors (Table A2 of the Appendix).

4. Results

4.1 Macroeconomics impacts

The CGE model captures the direct "first-round" impacts from relative soil productivity changes across regions. Thus, whilst the magnitude of the reverse productivity shocks provided by RUSLE is consistent in sign across all regions, the strength of this effect is highly heterogeneous. In general, those regions with larger (smaller) crop productivity deterioration will exhibit marginal relative deteriorations (improvements) in competitiveness, resulting in a marginal negative (positive) crop production trend. The main effect is the re-allocation of agricultural land between competing uses and the vertical transmission from upstream agriculture to downstream food activities (i.e., supply of inputs). In addition, the model also accounts for 'second-round' economy-wide ripple effects. For example, the redistribution of labour and capital from agricultural to non-agricultural uses affects their returns (i.e., wages and rents), and reflects on household incomes, production and macroeconomic growth.

Unless otherwise stated, all marginal impacts reported are in either percentage terms, quantity volumes or dollar values. The general pattern is that declining productivity in agriculture arising from the deterioration of the land factor will have a negative and unevenly distributed economic impact on the African economies.

GDP

Soil erosion is harmful to real gross domestic product (GDP) growth (Table 2) and significant differences emerge among countries. This is due to the combination of two factors, i.e., the magnitude of the country's land productivity shock and the relative size of the country's economy over the total African GDP. For example, Nigeria is projected to suffer the highest GDP loss due to soil erosion, under both scenarios, although its land productivity shock is not among the largest (-2.5%). Yet Nigeria is the biggest African economy, contributing to almost 20% to the total African GDP. The small economy of Rwanda will suffer a significant GDP loss in percentage terms, due to the large land productivity shock affecting the country (-6.9%).

Other significant losses will occur in countries located in Eastern Africa (Ethiopia, Uganda, Tanzania, Mozambique and Kenya). In the western part of the continent, Cote d'Ivoire is moderately affected (-0.46% and -0.72%), followed by Ghana. In northern and southern countries, the losses are relatively muted, given the smaller land productivity shocks.

In percentage terms to total GDP, the total loss amounts to -0.48% and -1.27% under the SSP2-A and SSP2-NA scenarios respectively. The assumption of land technology improvements in the baseline does affect the economic outcome, reducing by almost one third the total impact on GDP. This suggest that investing in long-term land productivity (e.g., irrigation facilities, cultivation techniques, machinery, human capital formation, etc.) may highly reduce the negative impact of exogenous events, like soil erosion.

Table 2. GDP impacts at the year 2050.

	SSP2-A (ml$)	SSP2-NA (ml$)	SSP2-A % GDP	SSP2-NA % GDP
Egypt	-34	-54	0.00	0.00
Morocco	-235	-367	-0.04	-0.06
Tunisia	-26	-54	-0.01	-0.02
RestNorthAf	-19	-35	-0.01	-0.01
BkFaso	-114	-304	-0.05	-0.15
Cameroon	-410	-851	-0.21	-0.44
CIvoire	-1,649	-2,559	-0.46	-0.71
Ghana	-905	-1,553	-0.13	-0.23
Nigeria	-40,216	-124,569	-1.67	-5.05
Senegal	-32	-91	-0.02	-0.06
RestWestAfr	-1,988	-3,710	-0.29	-0.55
CentAf	-119	-256	-0.07	-0.16
SouthCenAf	-214	-395	-0.08	-0.16
Ethiopia	-7,600	-16,660	-0.56	-1.23
Kenya	-1,367	-3,505	-0.29	-0.73
Madag	-973	-1,749	-0.73	-1.32
Malawi	-877	-1,619	-0.75	-1.39
Maur	-27	-68	-0.05	-0.12
Mozam	-2,095	-3,735	-0.34	-0.61
Rwanda	-3,738	-7,168	-2.47	-4.74
Tanzania	-1,981	-3,780	-0.49	-0.93
Uganda	-1,686	-3,797	-0.37	-0.83
Zambia	-107	-217	-0.10	-0.20
Zimbabwe	-103	-150	-0.11	-0.16
RestEastAf	-113	-311	-0.02	-0.04
Botswana	0	0	0.00	0.00
Namibia	-5	-11	-0.01	-0.03
South Africa	-18	56	0.00	0.01
RestSAC	-49	-92	-0.13	-0.24
TOTAL	***-66,697***	***-177,602***	***-0.48***	***-1.27***

Agri-food production

Agricultural production is negatively affected by soil erosion. Food production in the African continent will decrease by approximately 40 million tonnes in 2050, of which 27 million tonnes are crops (Table 3).[2] This is equivalent to about 1.5% of African agri-food production (1% for crops only), under the worst scenario (SSP2-NA).

According to the output of the RUSLE model, the countries located in Central Western Africa will suffer larger land productivity losses reflecting the larger soil

[2] Physical quantities are updated as ex-post calculations using endogenous changes in sector specific agricultural production volumes from the model over each period based on Ramankutty (2005). The original data source is FAOSTAT data on harvested areas and yields to derive the production quantities which are provided as a satellite account for MAGNET

erosion rates. As a result, Kenya, Malawi, Rest of Central Africa, Tanzania, Uganda and Rwanda are the major actors in the African crop output deterioration. The most affected country is, however, Nigeria, despite the relatively lower (yet significant) land productivity loss. This country is the biggest agricultural producer of the continent, contributing to 20% of African agricultural production. Nigeria alone will contribute to 40% (SSP2-A) and 46% (SPP2-NA) of total agricultural production loss.

On the contrary, countries from southern Africa will exhibit output increases, despite the negative productivity shock. These production gains are the result of a relatively more favourable production position of these countries compared to other regions, and relative comparative advantages arising from lower marginal land productivity losses.

Whilst land productivity losses are assumed uniform for all cropping activities within the same country, the resulting market impacts on crop activities within a region is highly heterogeneous. Horticulture is acutely affected by the pattern of soil erosion (Figure 2). This is mainly due to the large share of agricultural land employed in the production of vegetable and fruits, which amounts to almost 40% at the continental level, and to the larger shock affecting the main producers. The other crop activities will be, in general, less severely affected, although significant losses are expected for wheat and other cereals.

In livestock and food processing activities, the local 'second-round' model drivers discussed at the beginning of this section come to the fore. With decreased production in many cropping activities, feed costs are also higher because of soil erosion impacts. As a result, livestock, meat and dairy production is also lower. Similarly, the food processing sectors suffer the same negative cascade effect.

Table 3. Marginal changes in total agri-food production at the year 2050 (ths tonnes).

	Crops		***Livestock***		***Other Food***		***Total***	
Regions	*SSP2-A*	*SSP2-NA*	*SSP2-A*	*SSP2-NA*	*SSP2-A*	*SSP2-NA*	***SSP2-A***	***SSP2-NA***
Egypt	123.1	102.9	50.2	-14.0	111.3	-100.6	***284.6***	***-11.7***
Morocco	7.3	54.1	-3.4	-10.8	9.2	11.8	***13.1***	***55.0***
Tunisia	9.7	25.0	-0.9	-3.4	2.0	-0.0	***10.9***	***21.6***
RestNorthAf	11.7	59.4	-10.7	-22.4	-0.7	0.7	***0.2***	***37.7***
BkFaso	1.3	33.9	-5.9	-8.5	-22.8	-82.7	***-27.3***	***-57.3***
Cameroon	-470.3	-761.4	-8.0	-14.7	-28.1	-85.6	***-506.4***	***-861.7***
CIvoire	-1,135.8	-1,169.9	-5.9	-12.6	136.0	209.5	***-1,005.6***	***-973.1***
Ghana	-254.8	-347.4	0.8	1.1	12.8	4.6	***-241.3***	***-341.7***
Nigeria	-8,481.3	-6,862.2	-212.7	-150.7	-6,253.3	-10,124.3	***-14,947.3***	***-17,137.2***
Senegal	19.1	33.3	0.6	0.5	16.0	29.3	***35.7***	***63.2***
RestWestAfr	-1,116.8	-840.1	-196.5	-158.4	53.8	215.0	***-1,259.5***	***-783.5***
CentAf	-306.6	-482.5	-21.9	-39.0	-77.8	-148.9	***-406.3***	***-670.5***
SouthCenAf	-2,049.9	-3,243.4	-20.6	-26.7	-97.4	-139.7	***-2,168.0***	***-3,409.8***
Ethiopia	-1,088.1	-1,745.3	-346.6	-501.6	-892.0	-570.1	***-2,326.7***	***-2,817.0***
Kenya	-2,326.4	-3,452.1	-44.4	-153.5	-30.2	-31.4	***-2,401.0***	***-3,636.9***

Madag	-1,393.6	-1,290.5	-67.0	-88.7	-294.4	-337.9	***-1,755.1***	***-1,717.1***
Malawi	-2,563.4	-2,322.9	-40.2	-59.8	2.0	-35.5	***-2,601.7***	***-2,418.2***
Maur	-103.3	-213.0	-0.4	-1.2	-32.9	-69.0	***-136.6***	***-283.2***
Mozam	-909.6	-780.2	-24.2	-22.8	-34.3	-53.9	***-968.0***	***-856.9***
Rwanda	-1,894.7	-1,656.5	-32.5	-25.8	-78.1	-118.4	***-2,005.3***	***-1,800.7***
Tanzania	-2,317.3	-2,447.9	-159.0	-196.1	-384.2	-730.1	***-2,860.5***	***-3,374.0***
Uganda	-2,028.9	-1,945.9	-284.3	-223.9	-634.6	-508.3	***-2,947.8***	***-2,678.1***
Zambia	-10.1	40.1	-11.5	-9.3	35.8	53.1	***14.2***	***84.0***
Zimbabwe	-85.0	-121.9	-17.0	-24.5	-7.4	-12.5	***-109.4***	***-158.9***
RestEastAf	436.4	684.5	-5.5	-74.7	36.7	-53.1	***467.6***	***556.7***
Botswana	0.6	2.1	0.0	-0.1	0.1	0.1	***0.7***	***2.1***
Namibia	2.2	3.4	-2.3	-2.6	1.2	1.5	***1.1***	***2.3***
South Africa	496.5	2,382.4	-4.1	-37.1	113.3	138.7	***605.8***	***2,483.9***
RestSAC	-49.3	-77.6	-4.3	-6.2	-1.7	-1.8	***-55.3***	***-85.6***
Total	***-27,477.5 (-1.33%)***	***-26,339.9 (-1.47%)***	***-1,478.2 (-2.76%)***	***-1,887.3 (-4.0%)***	***-8,339.7 (-1.04)***	***-12,539.4 (-1.62%)***	***-37,295.5 (-1.28%)***	***-40,766.7 (-1.56%)***

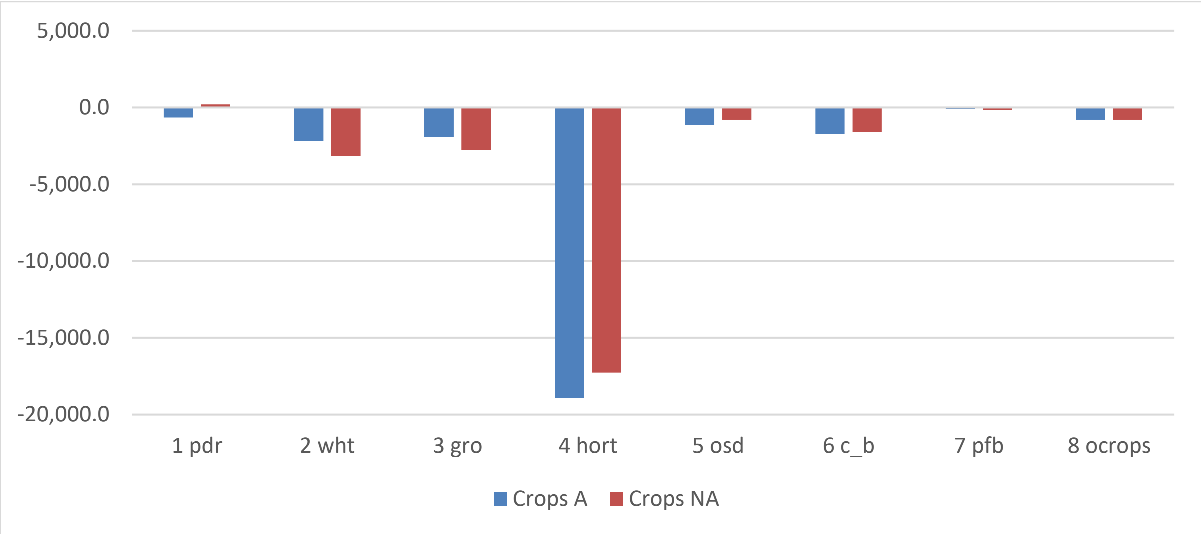

Figure 2. Marginal change in crop production (ths tonnes) by agricultural activities. 2050.

Land and water demand

Due to the deterioration of land productivity, the demand for more marginal land will increase in all regions, for a total of approximately 77,000 and 70,000 km^2 under the SSP2-A and SSP2-NA scenario respectively. More land is needed to compensate for the lower productivity induced by soil erosion. Whilst there are no significant differences by scenario, there is a large variability across countries (Figure 3). In general, where the availability of unused agricultural land is relatively more abundant, land demand expands more. For example, in the Central-South African region, only 34% of total agricultural land is employed in the base year; in some Eastern countries (i.e., Ethiopia, Tanzania, Zambia) this ratio amounts to about 45% (not shown). In North Africa, the average ratio is 96%, meaning that there is no much cropland left to be further employed in agricultural activities.

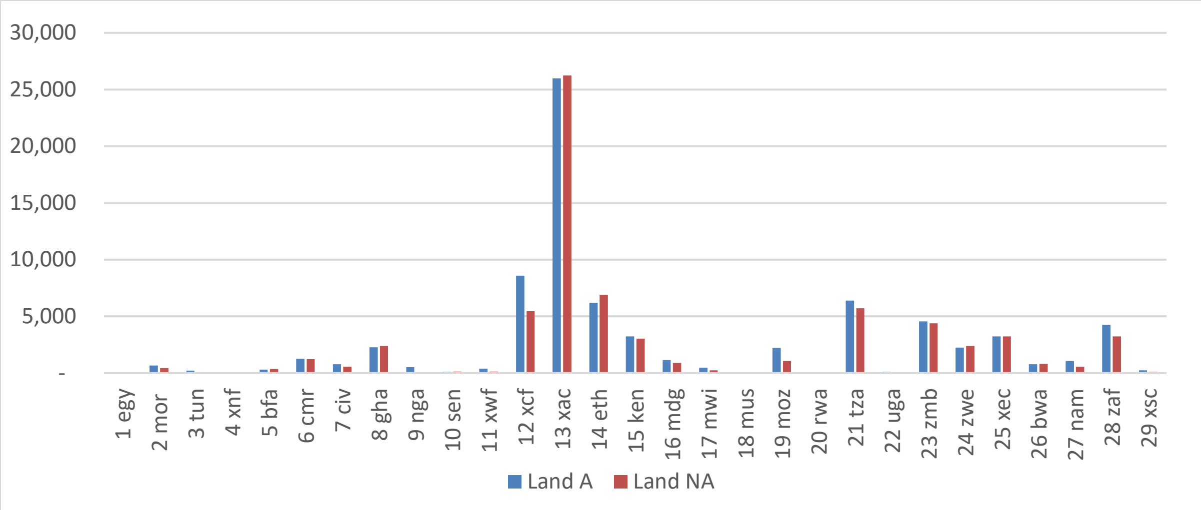

Figure 3. Marginal change in land demand (km^2).

The largest increases in land demand are expected in rain-fed cereals (about 10%) and horticulture (about 8%) activities, followed by oilseed and paddy rice (Table 4). Interestingly, the SSP2-NA scenario foresees a moderate increase in the share of land moved to the production of irrigated horticulture (2.3%). The absence of the land technology improvements assumption makes irrigated horticulture much more productive that the correspondent rain-fed sector, attracting land input.

An interesting result shown in Table 4 is the substantial increase in land employed in the cattle sector (72-75%), in response to soil erosion. Whilst the shock is uniformly applied to crop activities only, the land employed in the other sectors, in particular pastureland for livestock cattle, becomes relatively more productive compared to cropland, bringing about a significant increase in its marginal demand. However, as share of the total amount of land employed in the cattle sector in 2070, the large absolute increase in the marginal demand for land is only marginal (0.65%, not shown). The largest increases will be in the rice cultivation (1%) followed by other cereals (0.74%).

Table 4. Distribution of the total land demand change across agricultural activity (in km^2 and as % of total marginal increase).

Sectors	*SSP2-A (km^2)*	*SSP2-NA (km^2)*	*SSP2-A (%)*	*SSP2-NA (%)*
Rice	917	2,259	1.2%	3.2%
Wheat	-40	-516	-0.1%	-0.7%
OthCerls	7,450	6,780	9.6%	9.7%
Hortic	5,855	5,754	7.6%	8.3%
Oilseeds	973	2,360	1.3%	3.4%
Sugcane	57	29	0.1%	0.0%
PbFibers	-8	-160	0.0%	-0.2%
OthCrps	279	-1,004	0.4%	-1.4%
Cattle	55,883	52,475	72.3%	75.3%
Milk	3,995	-298	5.2%	-0.4%
Wool	1,094	398	1.4%	0.6%

Rice_i	151	200	0.2%	0.3%
Wheat_i	-46	-163	-0.1%	-0.2%
OthCerls_i	128	54	0.2%	0.1%
Hortic_i	547	1,576	0.7%	2.3%
Oilseeds_i	14	-45	0.0%	-0.1%
SugCane_i	24	-4	0.0%	0.0%
PbFibers_i	24	-12	0.0%	0.0%
OthCrps_i	23	-1	0.0%	0.0%
Total (km²)	***77,318***	***69,682***	***100%***	***100%***

The changes in the market conditions push the price of land up, with important differences between the two scenarios (Figures 4a and 4b). The average increase is double under the SSP2-NA scenario (5.3% against 2.5%). The absence of the land technology improvements assumption under this scenario makes land more expensive, with a peak of 25% in Nigeria, South Africa (12%), Uganda and Rwanda (10%).

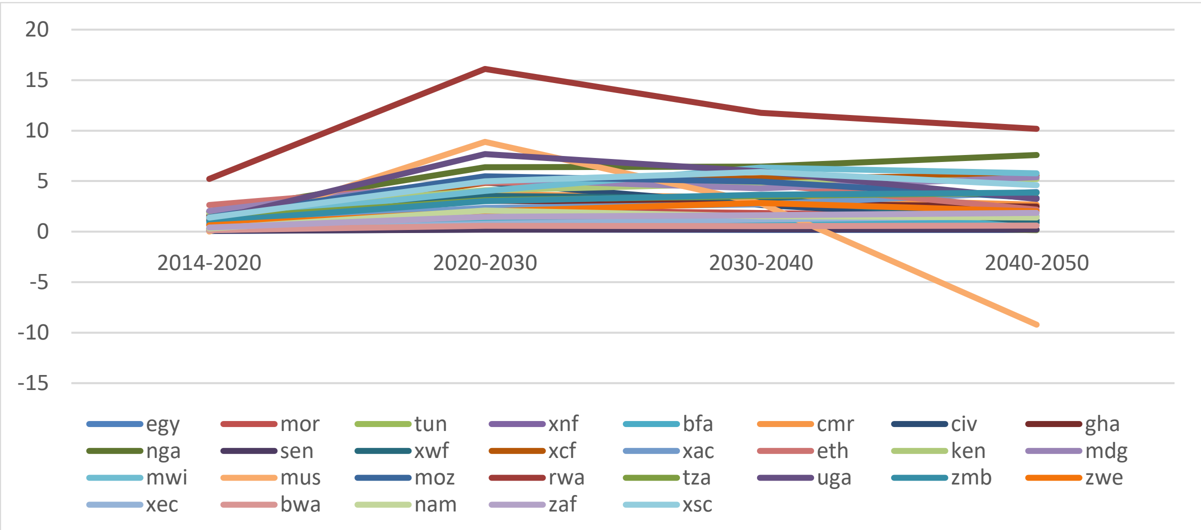

Figure 4a. Marginal change in land price over time, scenario SSP2-A (%).

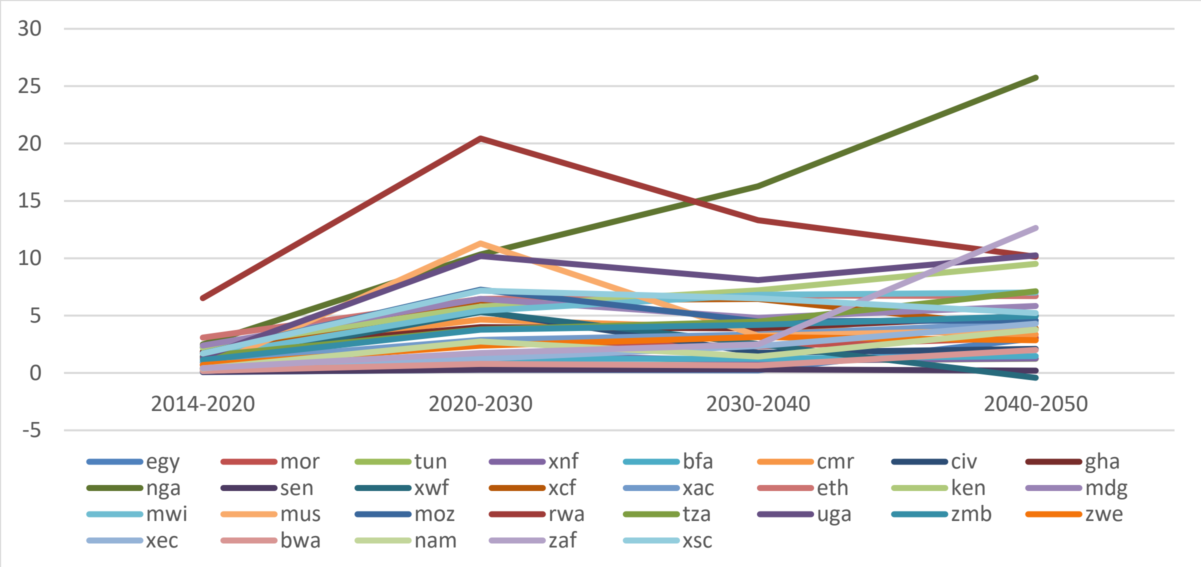

Figure 4b. Marginal change in land price over time, scenario SSP2-NA (%).

Prices, international trade and food security

Soil erosion does affect food prices, because of the deterioration in the availability of agri-food commodities in the local and international markets. As for land price, the assumption of improved land technology under scenario SSP2-A strongly dampens the soil erosion effect on prices.

The average increase in the world price of crops under the SSP2-NA scenario will be four times larger the SSP2-A average price (1.7% against 0.4%, Figures 5a and 5b).

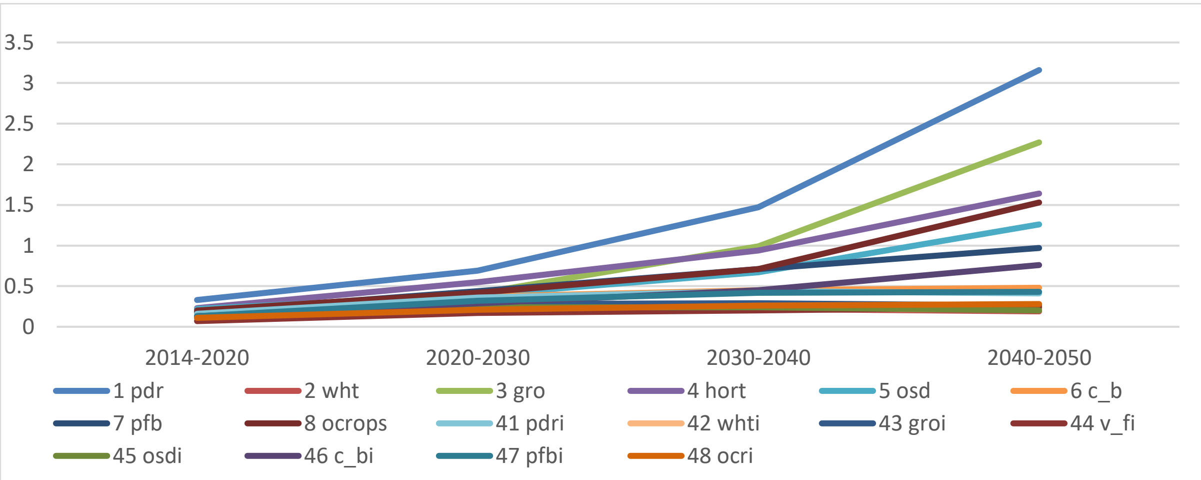

Figure 5a. Marginal change in the world price of crops over time, scenario SSP2-A (%).

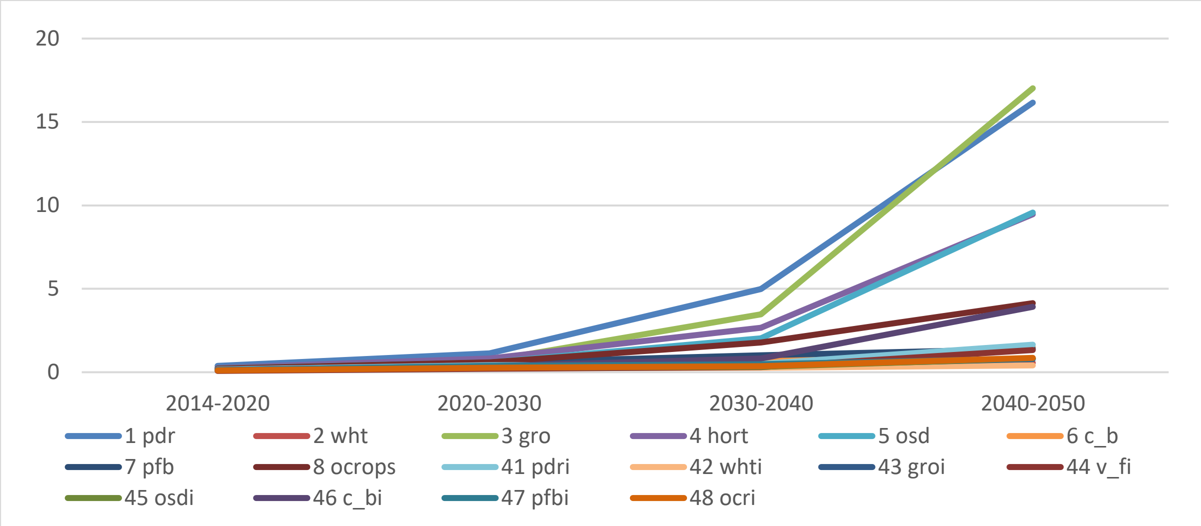

Figure 5b. Marginal change in the world price of crops over time, scenario SSP2-NA (%).

Similarly, the average price of food in the African continent will be three times larger under the SSP-NA scenario: 2.9% against 1% (Figure 6a and 6b). Nigeria and Rwanda are the countries with the highest increase.

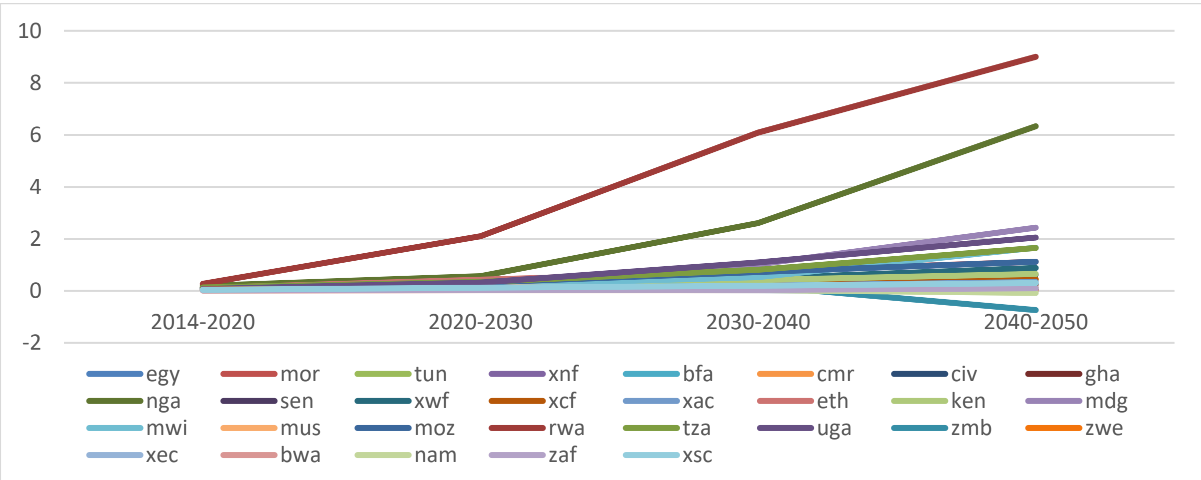

Figure 6a. Marginal change in the average price of food over time, scenario SSP2-A (%).

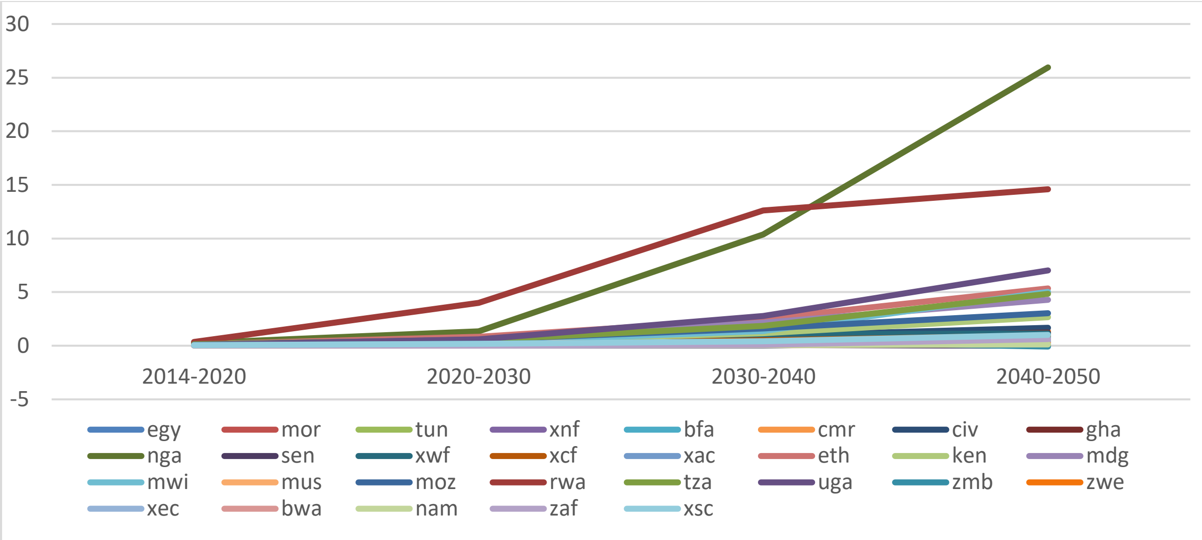

Figure 6b. Marginal change in the average price of food over time, scenario SSP2-NA (%).

The reduced crop production will inevitably affect trade balance, which will deteriorate in many African countries (Table 5). Total imports of crops will rise, relative to exports, due to the relatively larger land productivity loss compared to the rest of the world (see Table 1). In Nigeria, Cote d'Ivoire and Ethiopia the other crops sector drives the negative change, under both scenarios. In Egypt, where the productivity loss is zero and crop production is not affected, the net agro-trade position improves, in particular thanks to wheat and oilseeds exports.

Table 5. Marginal changes in agri-trade balance (crop exports-crop imports, ml US$).

Regions	*SSP2-A*	*SSP2-NA*	Regions	*SSP2-A*	*SSP2-NA*
Egypt	310.2	404.6	**Madag**	-58.4	-38.4
Morocco	12.6	40.0	**Malawi**	-71.7	-79.6
Tunisia	0.1	-0.5	**Maur**	8.4	4.5
RestNorthAf	-15.6	-18.7	**Mozam**	-46.2	-32.7
BkFaso	38.8	61.3	**Rwanda**	-59.0	-151.6
Cameroon	-28.8	-17.5	**Tanzania**	-160.4	-33.0
CIvoire	-372.8	-420.5	**Uganda**	-64.3	-19.0
Ghana	56.2	243.6	**Zambia**	-4.7	28.9
Nigeria	-391.0	-9345.2	**Zimbabwe**	-21.2	-13.0
Senegal	2.4	3.4	**RestEastAf**	-13.0	-7.6
RestWestAf	-34.9	-73.3	**Botswana**	0.7	2.6
CentAf	-7.8	-2.8	**Namibia**	0.5	-1.0
SouthCenAf	-13.5	-20.1	**SouthAfrica**	17.7	100.3
Ethiopia	-258.1	-278.3	**RestSAC**	-4.3	-7.9
Kenya	-51.5	-33.0	-	-	-

SDG indicators

African-relevant SDG indicators will worsen in response to soil erosion, in particular food access (SDG1) and per capita food consumption (SDG2) indexes. [TO BE COMPLETED]

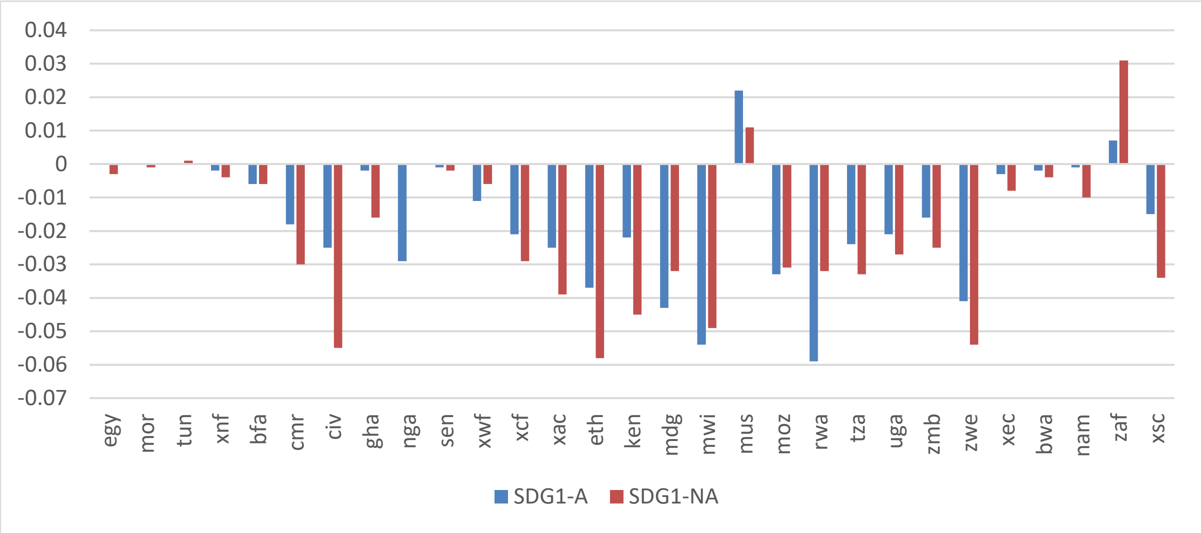

Figure 7. SDG1-Food access. Marginal change in the ratio of rural wage to cereals price by scenario.

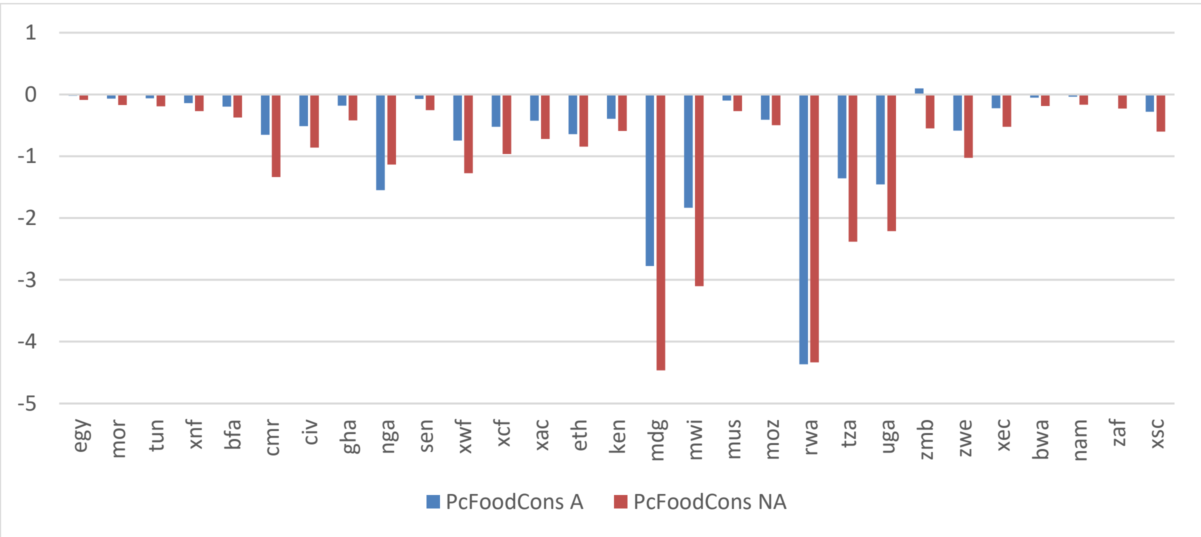

Figure 8. SDG2-Per capita food consumption. Marginal change by scenario.

5. Policy discussion and concluding remarks

To be developed. Some bullet points:

- Importance of improving land productivity to reduce impacts of soil erosion (see difference A scenario vs NA).

- In general, policies regulating soil use are lacking in many African countries and where policies exist, financing is often not a priority and/or implementation can be ineffective due to a lack of political will or a lack of implementation capacity (FAO, 2016).
- Soil erosion by water contributes to 46% of total soil erosion (ELD Initiative and UNEP, 2015). An assessment of soil erosion risk that focused only on water might provide incomplete information on the extent and severity of soil erosion and its impacts in the regions. That is, total economic losses are very likely to be larger than the preliminary outcome presented in this study
- Prevention policies: reforestation, composting (fertilize the soil with organic matter), contouring (plant crops across the slope), interseeding (growing a cover crop into a standing cash crop), vetiver grass (roots grow 2-4 meters downward)
- Main source of soil erosion in Africa: overgrazing of livestock, over-ploughing of farmland, global warming, wind erosion in dry flat areas, slash and burn agriculture, deforestation

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Appendix

A1. Additional input data and results

Table A1. Regional aggregation.

Countries and Regions	MAGNET regions
Egypt	Egypt
Morocco	Morocco
Tunisia	Tunisia
Rest of North Africa	Rest of North Africa
Burkina Faso	Burkina Faso
Cameroon	Cameroon
Cote d'Ivoire	Cote d'Ivoire
Ghana	Ghana
Nigeria	Nigeria
Senegal	Senegal
Rest of Western Africa	Benin, Guinea, Togo, Rest of Western Africa
Central Africa	Central Africa
South Central Africa	South Central Africa
Ethiopia	Ethiopia
Kenya	Kenya
Madagascar	Madagascar
Malawi	Malawi
Mauritius	Mauritius
Mozambique	Mozambique
Rwanda	Rwanda
Tanzania	Tanzania
Uganda	Uganda
Zambia	Zambia
Zimbabwe	Zimbabwe
Rest of Eastern Africa	Rest of Eastern Africa
Botswana	Botswana
Namibia	Namibia
South Africa	South Africa
Rest of South African Customs	Rest of South African Customs
EU27	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden
United Kingdom	United Kingdom
Rest of Europe	UK, Switzerland, Norway, Albania, Belarus, Ukraine, Rest of EFTA, Rest of Eastern Europe, Rest of Europe, Russian Federation
Americas	USA, Canada, Rest of North America, Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Perú, Uruguay, Venezuela, Rest of South America, Costa Rica, Dominican Republic, El Salvador, Guatemala, Honduras, Jamaica, Mexico, Nicaragua, Panama, Puerto Rico, Trinidad and Tobago, Caribbean, Rest of Central America
Asia	Japan, Republic of Korea, Mongolia, Cambodia, Laos, Malaysia, Philippines, Thailand, Vietnam, Bangladesh, Nepal, Sri Lanka, Pakistan, Rest of East Asia, Rest of South-East Asia, Rest of South Asia

Middle East	Bahrain, Iran, Israel, Jordan, Kuwait, Oman, Qatar, Saudi Arabia, UAE, Turkey, Rest of Western Asia
ROW	Australia, New Zealand, Rest of Oceania, Armenia, Azerbaijan, Georgia, Kazakhstan, Kyrgyzstan, Tajikistan, Rest of Former Soviet Union, Rest of the world

Table A2. Sector aggregation.

N.	***Sectors***	***MAGNET SECTORS***		***N.***	***Sectors***	***MAGNET SECTORS***	
1	Rice	PDR	Paddy rice	34	Manuf	fmp	Metal products
2	Wheat	WHT	Wheat	34	Manuf	ele	Computer, electronic and optic
3	Cereals	GRO	Cereal grains nec	34	Manuf	eeq	Electrical equipment
4	Veg_Frts	V_F	Vegetables, fruit, nuts	34	Manuf	ome	Machinery and equipment nec
5	Oilsds	OSD	Oil seeds	34	Manuf	mvh	Motor vehicles and parts
	Sugar	C_B	Sugar cane, sugar beet	34	Manuf	otn	Transport equipment nec
7	OthCrops	OCR	Crops nec	34	Manuf	omf	Manufactures nec
8	Pb_fibers	PFB	Plant-based fibers	34	Manuf	cns	Construction
9	Poultry	PLTRY	Poultry live animals	35	Petro	p_c	Petroleum, coal products
10	Beef_ctl	BFCTL	Beef cattle	36	Ely	ely	Electricity
11	Cattle	CTL	Cattle,sheep,goats,horses	36	Ely	ely_c	electricity from coal
12	OthLvs	OAP	Animal products nec	36	Ely	ely_g	electricity from gas
13	Milk	RMK	Raw milk	36	Ely	ely_n	electricity from nuclear
14	Wool	WOL	Wool, silk-worm cocoons	36	Ely	ely_h	electricity from hydro
15	Bf_meat	bfcmt	Beef meat	36	Ely	ely_w	electricity from wind and solar
16	Pltry_meat	poum	poultry meat	37	Gas_dist	gdt	Gas manufacture, distribution
17	Bov_meat	CMT	Bovine meat products	38	Food_serv	afs	Accommodation, food, services
18	OthMeat	OMT	Meat products nec	39	Serv	wtr	Water
19	VegOilFat	VOL	Vegetable oils and fats	39	Serv	trd	Trade
20	Dairy	MIL	Dairy products	39	Serv	otp	Transport nec
21	RicePro	PCR	Processed rice	39	Serv	wtp	Water transport
22	SugarPro	SUGAR	Sugar	39	Serv	atp	Air transport
22	SugarPro	mola	Molasse	39	Serv	whs	Warehousing and support activies
23	Feed	feed	Animal feed	39	Serv	cmn	Communication
24	VegOil	oilcak e	Oil cake byproduct of cvol used as animal feed	39	Serv	ofi	Financial services nec
25	Crude_Veg Oil	cvol	Crude vegetable oil	39	Serv	ins	Insurance
26	OthFood	OFD	Food products nec	39	Serv	rsa	Real estate activities
26	OthFood	fishm	Fish meal	39	Serv	obs	Business services nec
26	OthFood	Fishp	Fish processing	39	Serv	ros	Recreational and other service
27	Bev_Tob	B_T	Beverages and tobacco products	39	Serv	osg	Public Administration and defence
28	Forestry	FRS	Forestry	39	Serv	edu	Education
29	Fish	FSH	Fishing	39	Serv	hht	Human health and social work
29	Fish	Diad	Diadromis fish	39	Serv	dwe	Dwellings
29	Fish	Fresh	Fresh water fish	40	Fert	fert_n	fertilizer nutrient n
29	Fish	Crust	Crustaceans	40	Fert	fert_p	fertilizer nutrient p
29	Fish	Marin	Marin fish	40	Fert	fert_k	fertilizer nutrient k
29	Fish	Molus	Molusks	41	Biod	biod	Biodiesel
30	Coal	COA	Coal	41	Biod	bf_o	biofuel feedstock oils

31	Oil	OIL	Oil	42	Biog	biog	Biogasoline
32	Gas	GAS	Gas	42	Biog	bf_g	biofuel feedstock grains
33	Light_Mnf	tex	Textiles	42	Biog	bf_s	biofuel feedstock sugar
33	Light_Mnf	wap	Wearing apparel	42	Biog	bf_m	biofuel feedstock molasse
33	Light_Mnf	lea	Leather products	43	DDgs	ddgs	Biogasoline byproduct
33	Light_Mnf	lum	Wood products	44	Rice_i	pdri	irrigated rice
33	Light_Mnf	ppp	Paper products, publishing	45	Wheat_i	whti	irrigated wheat
34	Manuf	oxt	Minerals nec	46	Cereals_i	groi	irrigated other grains
34	Manuf	chm	Chemical products	47	Veg_Frts_i	v_fi	irrigated fruits and veg
34	Manuf	bph	Basic pharmaceutical products	48	Oilsds_i	osdi	irrigated oilseeds
34	Manuf	rpp	Rubber and plastic products	49	Sugar_i	c_bi	irrigated sugar beet and cane
34	Manuf	nmm	Mineral products nec	50	OthCrops_i	ocri	irrigated other crops
34	Manuf	i_s	Ferrous metals	51	Pb_fibers_i	pfbi	irrigated plant based fibres
34	Manuf	nfm	Metals nec	-	-	-	-

A2. Agricultural land supply in MAGNET

In the standard CGE model treatments, land supply is exogenous in each region. However, in reality, agricultural land supply can adjust due to the idling of agricultural land or the conversion of land to agricultural uses. The supply of agricultural land depends on its biophysical suitability, institutional factors (agricultural, urban and nature protection policies) and land price (Tabeau et al., 2006, p.3). Biophysical suitability refers to climate, soil and water conditions that make a plot of land suitable for cultivation. Accordingly, biophysical parameters will define the maximum potentially available land surface that can be used for agricultural purposes (the asymptote in Figure A2). At the outset, the most productive land is used first. With increases in land usage, farmers must employ less productive land implying that the marginal cost of conversion rises, which is reflected in a higher land price. This relationship between land usage and prices gives an upward sloping supply curve (see Figure A2).

Any point along the supply curve is feasible from an agronomic point of view, however, every country/region will be positioned on a specific point, representing the current relative use of land in the agricultural sector. When the region is currently using a low proportion of all the potentially available land, any increase in demand for agricultural land will lead to conversion towards agricultural uses at a modest increase in price (e.g. point A in Figure A2). In this zone of the supply curve, the supply elasticity is relatively higher, and the marginal cost of converting non-agricultural land into agricultural land is relatively lower. However, when a region is currently cultivating most of the available land (e.g. point B in Figure A2), any increase in demand that requires the conversion of the scarce non-used land to agriculture, will lead to the conversion of the least productive land and at a relatively higher marginal cost (land supply elasticity is low).

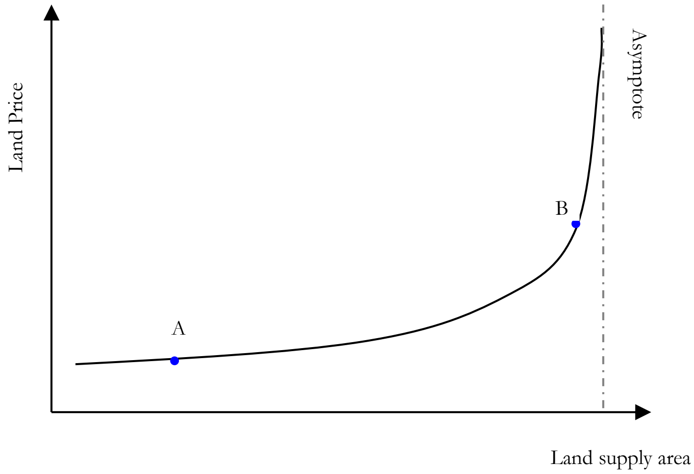

Figure A2: Theoretical agricultural land supply curve

The assumed land supply function for each of the regions in the MAGNET model is:

$$L = A - \frac{B}{P} \quad \text{(A1)}$$

where L is land supply, P is the real rental value of land, A is the maximum available agricultural land area (the land asymptote), and B is a positive parameter. The resulting land supply elasticity E_s in respect of land price is defined as:

$$E_s = \frac{A}{L} - 1 \quad \text{(A2)}$$

In Tabeau et al. (2017), a full list of the land supply elasticities used in MAGNET can be consulted.