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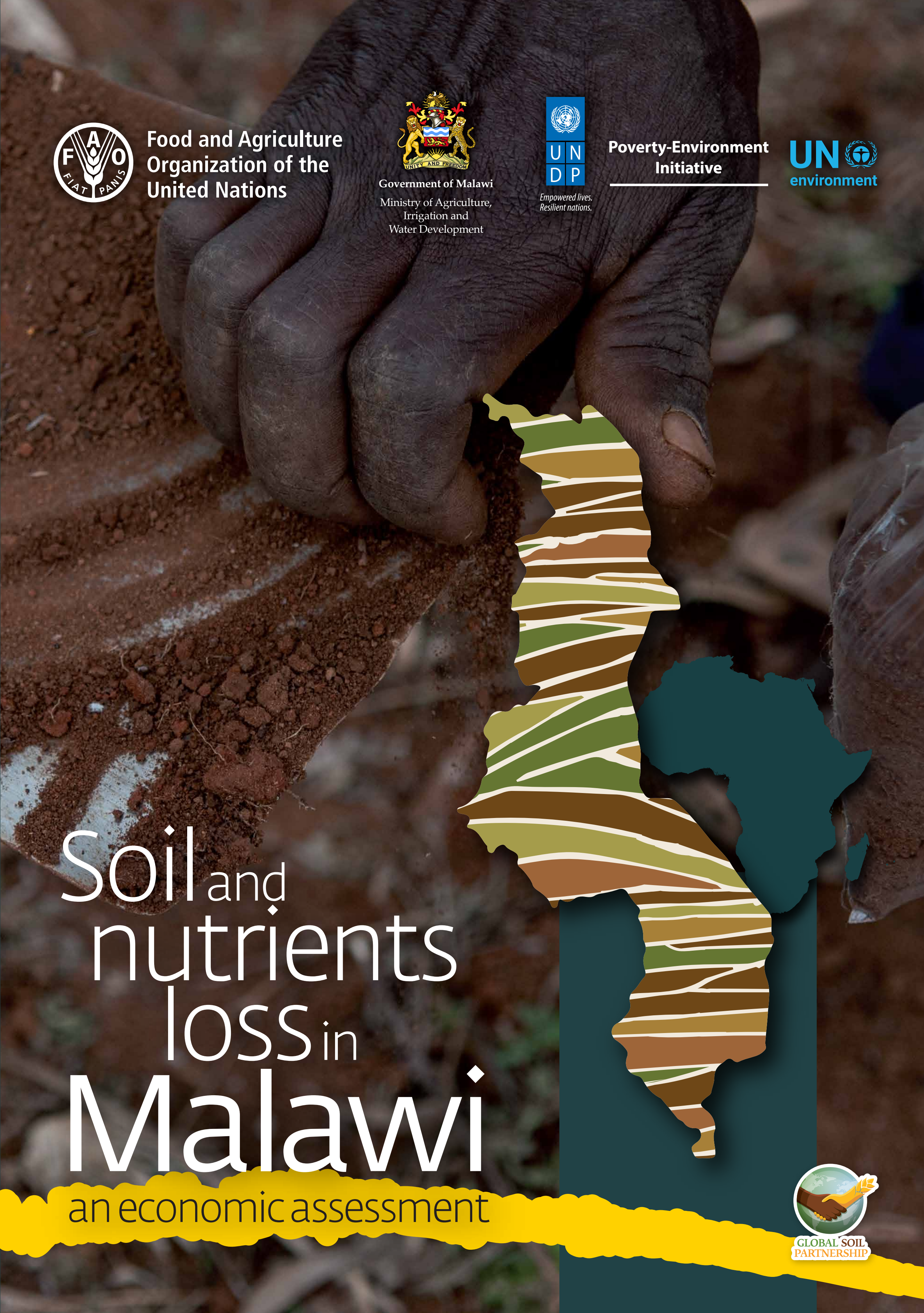

Soil and nutrients loss in Malawi

an economic assessment

GLOBAL SOIL
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Soil and nutrients loss in Malawi: an economic assessment

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Abbreviations

ADD	Agricultural Development Division
AEZ	Agro Ecological Zones
ARC2	Africa Rainfall Climatology
CA	Conservation Agriculture
CAN	Calcium Ammonium Nitrate
CGE	Computable General Equilibrium
DAP	Di-Ammonium Phosphate
DSM	Digital Soil Mapping
EA	Enumeration Area
EHU	Erosion Hazard Units
EPA	Extension Planning Area
ESR	Endogenous Switching Regression Model
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
LSMA	Living Standard Measurement Assessment
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FISP	Farm Input Subsidy Program
GDP	Gross Domestic Product
GoM	Government of Malawi
GSP	Global Soil Partnership
GTS	Global Telecommunication System
HH	Household
IFDC	International Fertiliser Development Centre
IFPRI	International Food Policy Research Institute

HIS	Integrated Household Survey
ISFM	Integrated Soil Fertility Management
ISRIC	International Soil Reference and Information Centre
ISSS	International Society of Soil Science
LRCD	Land Resource Conservation Department of the Government of Malawi
MEMP	Malawi Environmental Monitoring Program
MPTF	Maize Productivity Task Force
MV	Modern Varieties
MWK	Malawian Kwacha
NPK	Nitrogen Phosphorous and Potassium
NSO	National Statistics Office
OC	Organic Carbon
OM	Organic Matter
SAP	Sustainable Agricultural Practice
SPEI	Standardized Precipitation Evapotranspiration Index
SLEMSA -	Soil Loss Estimation Model for Southern Africa
UNDP	United Nations Development Programme
USDA	United States Department of Agriculture

Executive Summary

Soil and nutrients loss are among the major impediments to a stable and sustained agricultural development in Malawi. They have historically affected the country but the high population growth, rapid deforestation, overgrazing and ploughing, combined with the impacts of climate change, such as temperature increases and changing precipitation patterns, are increasing the impact of these events that harm agricultural growth. This report analyses the economic impact of both soil and nutrient loss in Malawi with new country-representative data on soil and nutrients loss indicators collected through field surveys, merged with detailed climatic data and socio-economic information. It translates soil loss/nutrient loss into yield loss and estimates the economic impact of loss on agricultural production as a result of soil degradation, followed by the identification of best practices to mitigate the soil and nutrient loss events.

The study applies both partial and general equilibrium analyses soft linking an econometric model to a Computable General Equilibrium (CGE) model.

A quantile model is estimated with a production function accounting for all the inputs, other crops cultivated on the plot and the area cultivated so as to implicitly facilitate the generalization of results from the effect on total production to the productivity (yield). The same methodology is applied to evaluate the impact of soil and nutrient loss on broader measures of welfare, such as the total per capita consumption, caloric intake and poverty ratio. All the estimates are completed with interaction and squared terms that allows each to catch marginal effects (ME) of an increase in soil and nutrient loss when the HH is female headed or when associated with a certain agroecological zone or district. This is to provide differentiated impacts on marginalized segments of the population. These results are then translated in impact on farmers' profitability when they apply suggested agricultural practices. The soil nutrient loss scenarios are then defined as moderate or severe.

New analysis suggests that the impacts of soil/nutrient loss in Malawi may be larger than previously estimated.

The analysis by district shows that the largest expected impacts affect the southern districts and the warmer agro-ecological zones. When assuming a loss of 10 tons/hectare as a baseline scenario, an average projected loss of 22 tons/hectare yields results, with a range of 32-61% loss in maize productivity. When imposing a severe scenario with an average loss of 40 tons/hectare, the projected productivity loss ranges from 39% to 77% with regard to the baseline Finally, when assuming the moderate scenario of 22 tons/hectare as a baseline and comparing it with the severe scenario at 40 tons/hectare, the expected loss in maize productivity ranges from about 9% to 44%.

Considering moderate and severe scenarios of soil loss, direct costs are significant and range between 0.6-2.1% of the GDP of Malawi.

A 10% increase in soil loss would produce monetary losses of about 0.26% of the GDP of Malawi and 0.42% of the total agricultural production value. Higher soil loss values lead to larger impacts: in the second scenario, a 25% increase in soil loss would result in monetary impacts of about 0.64% of the GDP and about 1% of the agricultural production. The worst case scenario would result in a 50% increase in soil loss yields which translates to monetary losses corresponding to about 1.28% of GDP and 2.1% of the total agricultural production value.

An additional 1.6% reduction of GDP might occur considering the loss of Nitrogen, Phosphorous and Potassium under a moderate scenario.

Combining all the reductions of values associated with the switch from the current conditions to a severe increase in nutrient loss, and summing up these effects for all nutrients, the result would be a reduction in the GDP by 1.6% and a reduction of agricultural production value equal to 3.4%. Nevertheless, disaggregating these figures, we obtain differentiated impacts, because Nitrogen losses can be isolated as the driving factor behind productivity loss.

Autonomous or market driven farmers adaptation to soil loss events, as estimated with a general equilibrium model, might reduce the GDP costs by up to 70%.

A general equilibrium model is employed to identify how market agents (i.e. firms, farmers, consumers and the government) react and adjust to the initial soil loss productivity shock. Results of the model simulations show that welfare and GDP fall due to a decline in land productivity by 0.10%-0.55%, whereas crop prices increase. However, compared to direct-costs, they are significantly lower, which suggests that the Government should prioritize policies that promote labour sectoral mobility and investments in education, in order to balance the negative effects on the agricultural sector.

The largest and most significant effects are concentrated along the lower deciles of the outcome distributions and in female headed households (HH).

This is likely caused by the fact that poorer farmers have lower access to other income sources and are therefore strictly dependent on the agricultural and agro-ecological conditions. This interpretation is also confirmed by the coefficients of climatic shocks which are negative drivers of per capita consumption levels only for the lower deciles. The negative impact of soil loss on per capita consumption in the first deciles is around 0.14% for a 1% increase of soil loss. On the contrary, higher quantiles are not significantly affected by soil loss, given that wealthier HHs can rely on other sources of income other than agriculture. The impact of soil loss on female headed HH is more than double that of a male headed HH. (all the words household from now on should be changed by HH). Finally, it is worth noting that the negative impacts of the soil loss severely affect per capita caloric intake, with the largest effects impacting the poorest individuals.

Among antierosion practices, vetiver grass and terraces are the most successful strategies for farmers to tackle events of extreme soil loss while for nutrients, crop diversification and legumes intercropping can significantly reduce the loss of Phosphorus and Nitrogen.

In all scenarios of soil loss the highest economic mitigation impact results from the adoption of vetiver grass, followed by terraces, tree belts and bunds. In each of the three soil loss scenarios, as well as in the status quo (current loss rate), the most effective practices are represented by vetiver grass and terraces. In particular, in the status quo, the adoption of these two practices increases productivity by about 275 kg/ha and 200 kg/ha in comparison with non-adoption. Tree belts and erosion control bunds produce much lower impacts in terms of productivity growth, which range from about 80 to 120 kg/ha, depending on the severity of the soil loss scenario.

Current application rates of NPK (Chitowe) fertilizers are inadequate to cope with a moderate increase in Nitrogen loss, even with FISP subsidized price.

The study estimates the profitability for the current level of N loss (4 kg/ha) and for a projected loss of 22 kg/ha. Under current NPK and Urea application rates, an increase of N loss would reduce profitability by around 10.7% (from 65000 MWK to 58000 MWK). However, using the profit maximizing recommended rates (around 170 kg/ha) would increase profits by 13.1%.

The "social" (farmers + government) benefit/cost (B/C) ratio of bringing all current FISP recipients to the recommended rates, as soil loss increases and the price of fertilizers is subsidized, is 0.42. This course of action would require the government to double the current FISP.

On the contrary, increasing access to commercial fertilizers, while excluding those HHs more likely to buy from the private sector, would reduce Government costs. A share of vouchers from current recipients that are more likely to purchase commercial fertilizers (plot owners, highly educated and large HHs) could be transferred to non-recipients that are less likely to adopt commercial fertilizers. With this adjustment, the projected social B/C ratio improves from 0.42 to 0.89, moving closer to 1. Also transferring vouchers from well-endowed HHs in warm agroecological zones, which are less profitable in terms of fertilizer use, to poor HHs in cool subhumid zones, the most profitable, would increase the equity of FISP but the B/C ratio improvement would be limited (from 0.42 to 0.54).

Incentivize the practice of legume intercropping, which reduces profit maximizing fertilizer requirements and can hugely increase the social benefit/cost ratio, to more than 4. In this case, the current FISP provision of fertilizers could remain stable.

Intercropping significantly reduces the ferilizer requirements for both FISP participants and non-participants, increasing the net crop incomes of all the groups (around 39% on average for all the groups). This can allow for a more efficient re-formulation of subsidy distribution among farmers: well-endowed farmers can receive less from the Government, and increased distribution can be given to the Middle class. Bundling modern practices together with more responsive sustainable practices requires minimal costs to the Government (cost of subsidizing legume seeds), and generates a very high return.

1 Introduction

Land degradation is a broad process that encompasses all changes in the capacity of ecosystems affected by land degradation to provide biological, social, and economic services. Water and wind erosion are the most relevant processes causing topsoil loss and land degradation (UNEP, 2015; Oldeman *et al.*, 1991). Soil erosion is instead defined as the absolute loss of topsoil and nutrients carried away from the land by water or wind and transported to other surfaces. It is a natural process especially in steep areas, but poor management practices can increase the potential of soils to erode (Panagos *et al.*, 2015).

Soil loss can disrupt the natural soil balance leading to a decrease in the productive potential of agricultural land (Pimentel *et al.*, 1995). Some consequences include (Telles *et al.*, 2011): a decrease in yield per unit of applied inputs, loss or decrease in farmers' incomes and profit, reduction in crop and livestock farming activities, drop in the value of the agricultural land, pollution and destruction of water resources and public assets and migration of rural populations to urban areas.

Although soil erosion is a natural occurrence, it is usually caused or increased by human activities that remove vegetation cover, such as deforestation, overgrazing, and other management practices such as ploughing. Drivers of soil and nutrient loss are distinguished as either proximate or underlying. Proximate drivers are the ones that impact land ecosystems directly: climatic conditions and extreme weather events (droughts and floods, fires), unsuitable land uses and land management practices (D'Odorico *et al.* 2013; Wale and Dejenie, 2013). Underlying drivers are of anthropogenic nature, and include: land tenure, poverty, population density and weak policy/regulatory environment in the agricultural and environmental sectors (Nkonya *et al.*, 2016).

This loss results in a decrease in agricultural productivity, increased expenditure on fertilizers, and a general decline in profitability of crop production. However, looking for the term "soil erosion" in peer-reviewed literature leads to around 1,030,000 results (10 May 2018). However, looking for the topic "soil erosion costs" only results in 3,930 publications (a share of 0.4%). At the same time, a search on "soil nutrient loss" results in 2,360 publications (only 642 if we make a combined search of the terms "costs" and "soil nutrient loss"). These low percentages demonstrate that research on soil loss focused more on the physical aspect rather than on the economic one, and that the role of nutrients has not yet been properly investigated from an economic perspective. High population growth, rapid deforestation, widespread soil erosion, combined with the impacts of climate change, such as temperature increases and changing precipitation patterns, are harming agricultural growth. The impacts are expected to worsen in the coming decades, when temperatures will reach the heat threshold for some crops and extended dry periods will become more common. Moreover, due to the changing precipitation patterns, rainfall is likely to become more erratic and concentrated which can cause flooding and further crop damage. Overall, climate change is expected to reduce global food supply and have major implications on human welfare, harming developmental progress across international sectors.

Sub-Saharan Africa has been historically affected by land degradation and in many rural countries, economic stagnation can be attributed to low levels of agricultural productivity. In Malawi, according to the World Bank, the agricultural sector represents around 30% of total 2015 value added (WDI 2017). Cassava, maize, potatoes and sugar cane are the major crops in terms of production value. Rural population is predominant and accounts for more than 80% of total population (WDI 2017). Given the size of the agricultural sector in the Malawian economy, soil and nutrient loss represent a major limitation to the overall economic development.

The aim of this work is to analyse the economic impact of both soil and nutrient loss in Malawi with new and relevant country data on soil loss and nutrient indicators collected through field surveys, merged with detailed climatic data and socio-economic information. It translates soil and nutrient loss into yield loss and estimates their economic impact on agricultural production before identifying the best practices to mitigate the issue of soil loss.

Building on this analysis, this report tries to answer some fundamental questions for policy makers. First, what type of impact do soil and nutrient loss have on agricultural productivity? Second, what type of practices can be implemented to mitigate these impacts? According to these basic questions, other issues were investigated. If it is true that a soil and nutrient loss, have a detrimental impact on the primary sector, how do these phenomena influence broader measure of welfare and food security in a rural country such as Malawi? Moreover, considering the great effort so far carried out by the government to incentivize, at the national level, modern agricultural practices (see the FISP), is it possible to verify whether the distribution of these practices has been set up efficiently in regards to reducing soil nutrient loss across the country? Which groups of the population are most affected by soil degradation? How do these impacts at the micro level translate into the macro level expressed in terms of sectoral adjustments, net imports and prices?

To answer these questions, the present research innovates on several aspects. It relies on national data (LSMA-ISA survey) to estimate both proximate and underlying drivers of the effects of soil and nutrient loss on agricultural production. The economic impact of the loss is considered at the micro, district and national level on the basis of microeconometric analysis while, at the same time, a computable general equilibrium analysis provides an assessment of the impact of soil loss on trade, prices and sectoral adjustments. State-of-the-art climatic indicators (SPEI) are employed to identify climate anomalies that influence the severity of nutrient loss. Potential correlation and complementarities between nutrient loss and practices are also accounted for.

The next section concentrates on literature background on soil and nutrient loss and practices to mitigate their impact. Section 3 illustrates the source of data, while Section 4 reports in brief the methodologies adopted. Results are presented in Section 5, 6, 7, 8 and 9. Sections 10 represents the conclusion of this study.

2 Background

2.1 Land degradation and soil erosion

Drivers of land degradation are numerous (Lambin and Geist 2006). According to Nkonya *et al.* (2016), they can be distinguished in two classes: proximate and underlying. Proximate drivers are those that directly impact land ecosystems. Examples include climatic conditions and extreme weather events such as droughts and floods, fires, unsuitable land uses and land management practices. Fires are common in dry and semi-arid lands (D'Odorico *et al.*, 2013) leading to serious soil loss problems. Unexpected rainfall can also induce salinization of the soil (Wale and Dejenie, 2013). Deforestation is often correlated with an increasing demand for agricultural land, charcoal and fuel-wood, construction materials, large-scale and resettlement of people in forested areas. In turn this is often a consequence of unsuccessful policy measures to preserve forests. Soil erosion reduces the fertility and productivity of soil as it removes organic matter and important nutrients. It changes the physical, chemical, and biological characteristics of soil and leads to a decline in potential agricultural productivity and gives rise to concerns about food security (Panagos *et al.* 2018). Water erosion is the most relevant process causing topsoil loss and land degradation. It can be encountered all over the world but has different intensity and scope depending on climatic and physical conditions as well as human activities (Oldeman, *et al.*, 1991). Winds can also alter and transfer topsoil. Wind erosion is most prevalent in arid and semi-arid zones, but humid regions are not exempt, as the phenomenon is caused or increased by human activities that remove vegetation cover, such as deforestation, overgrazing, and ploughing (Oldeman, *et al.*, 1991).

Salinization mainly arises on irrigated land and it is a consequence of high concentrations of mineral salts left on the surface after the evaporation of water (UNEP, 2015). According to Nkonya *et al.* (2016), salinization affects 950 million ha in arid and semi-arid regions, around 33 per cent of the world's potentially arable land area. Mineral salts damage plants and affect soil fertility, reducing agricultural productivity and yield (Jones, *et al.*, 2013).

Agricultural and management practices such as poorly managed irrigation and over-exploitation can lead to soil nutrient loss and result in soil and land degradation, while the extreme use of agrochemicals can pollute soils and degrade the land (UNCCD, 2012). Furthermore, the excessive use of heavy machinery and repeated trampling by grazing animals can lead to soil compaction, a form of physical degradation due to the reorganisation of soil micro and macro aggregates, which are deformed or even destroyed as a result of pressure on the surface of the soil (Jones, *et al.*, 2013).

Turning to the underlying causes of land degradation and soil erosion, key elements are land tenure, poverty, population density and weak policy and regulatory environment in the agricultural and environmental sectors. Insecure land tenure may disincentive investment in sustainable agricultural practices and technologies (Nkonya *et al.*, 2016). Similarly, a growing population without proper land management will exhaust the land's capacity to provide ecosystem services. Moreover, population pressure has been found to increase agricultural intensification and land productivity as well as technological and institutional innovations that reduce natural resource degradation (Nkonya *et al.*, 2016).

2.2 Soil and nutrient loss in Malawi

Soil loss is a major threat to agricultural development in Malawi, and the size of the agricultural sector in the Malawian economy renders it a major limitation to the overall economic development of the country. Soil loss reduces cultivable soil depth, but also fertile soils from farmlands. The net effect is a loss in agricultural productivity, increased expenditure on fertilizers, and a general decline in profitability of crop production.

Although not entirely cross-compared, the soil loss studies in Malawi point to an increasing trend over the years. This is a challenge for a country that is highly dependent on agriculture, and therefore soils. There is potential for huge economic losses associated with the increasing trend in soil loss. A study by Yaron *et al.* (2011) reports a conservative estimate of the annual on-site loss of agricultural productivity as a result of soil loss to cost as much as MK7.5 billion (US$54 million or 1.6% of GDP). A detailed economic analysis of the impacts of soil loss on the country is necessary to fully understand the extent of soil loss in the country (or positive gains that can be realized if soil loss was controlled).

The first studies date back to the 80's and are based on experimental plots. Amphlett (1984) performed soil loss studies in different plots in south Malawi (Bvumbwe, Mindawo, and Mphezo basins) and found seasonal soil loss rates between 0.15 and 16 t/ha/year. Two other studies (Kasambara, 1984 and Machira, 1984) have been conducted in different parts of the country and found soil loss rates ranging from 0 to 50t/ha/year. Khonje and Machira (1987) used the SLEMSA model to make a relative assessment of the risk of erosion expressed in

Erosion Hazard Units (EHU). They applied the model sequentially for 10 km^2 grid cells to map Erosion Hazards Units for the entire country. Then, for each grid, they converted the EHU into soil loss, resulting in a national average rate of soil loss of 33 t/ha/year.

Other key studies on soil erosion are: World Bank (1992), Malawi Environmental Monitoring Program (1996), Bishop (1995) and Nakhumwa (2004).

The World Bank conducted a desk study in 1992 to assess soil loss in all eight Agricultural Development Divisions (ADDs) and their implications on yield. The study estimated soil erosion at 20 t/ha/year with an average yield loss for the agriculture sector ranging from 4.0% for low impact to 11.3% for high impact areas. Some areas such as Karonga and Blantyre had yield loss as high as 15.6% and 15.7% respectively. Yet other areas had lower erosion rates. For example, Salima and Machinga had 16 and 13 t/ha/year or erosion with the lowest impacts of 3.1% and 2.6% on average yield loss respectively. Although the national rate should be determined with care, as pointed out by Yaron *et al.* (2011) given the methodology used (secondary data analysis) and Malawi's diversity in terms of erosion characteristics, the major objective of the study was to demonstrate heterogeneity in soil loss rates in different ADDs.

Bishop (1995) presents results from different case studies of the on-site economic cost of soil erosion on farm land, finding rates of soil loss ranging from 0.1 to 54.2 t/ha/year.

The Malawi Environmental Monitoring Program (MEMP) primarily aimed to assess "the potential environmental impacts of increased smallholder production of burley tobacco" in terms of soil erosion, water quality, and deforestation. The liberalization of burley tobacco was pursued to increase smallholder participation in the cultivation of this cash crop. However, burley is also an erosion inducing crop and requires considerable levels of soil nutrients. Thus the liberalization could potentially reduce soil fertility and increase the level of erosion. For this reason, the program monitored both control plots (small fenced-in plots where conditions can be controlled) and farmers' plots. The Soil Loss Estimation Model for Southern Africa (SLEMSA) was used to establish the rates of soil and nutrient loss associated with cropping practices in sites in Nkhata Bay, Kasungu, Ntcheu, and Mangochi districts. The study was conducted in five small catchments located in various parts of the country and found the soil loss rate between 1 and 5 t/ha/year (Mahmoud and Burger 1998).

As reported in Yaron *et al.* (2011), Mlava *et al.* (2010) found that soil erosion in the Linthipe catchment in 1994 was ranging between negligible values and 50 t/ha/year. In 2008, the upper range value increased to 57 t/ha/year. In the Lower Shire catchment, estimates of soil erosion were between 3–31 t/ha/year in 2008. On slopes of less than 20% in the Linthipe catchment, they found a weighted average soil erosion of 12 t/ha/annum which is lower than the one estimated by World Bank (1992). However, when slopes greater than 20% were included, Mlava *et al.* (2010) found an estimated soil erosion of 19.9 t/ha/annum, which was within the ranges documented by the World Bank (1992), and Bishop (1995).

Soil erosion impacts agriculture as it results in a depletion of soil nutrients needed for an optimal growth of the crop. To investigate this issue, Nakhumwa (2004) analysed 120 farmers from Nkhata Bay district in northern Malawi and 143 from Mangochi district in southern Malawi. The sample consisted of 50% respondents who were still using conservation technologies two years after the phasing out of the MEMP project, and 50% who had stopped using the technologies. Other than collecting socio-economic data, a soil survey was conducted to establish soil characteristics of the sites and the collected data were linked to secondary data from other sources to estimate soil erosion using the SLEMSA.

Under current practice, the study showed that there was soil loss of 1.4 tons per hectare of nitrogen against 1.6 tons per hectare under dynamic optimization. Under the dynamic optimization scenario, farmers would use more fertilizers (49 vs. 15kg per hectare) but they would also double their yield (1.5 tons per hectare) compared to that of farmers under the current practices (0.75 tons per hectare). More soil was being eroded under the current practice (0.2 cm of soil per hectare) than under dynamic optimization (0.15 cm per hectare). However, one of the most important findings was that under current smallholder soil management practices, the annual loss of productive land value was of US$21 per hectare. This is equivalent to 14% of Malawi's agricultural GDP, or MK4.5 billion (US$41 million).

Benin et al (2008) used the CGE model of the International Food Policy Research Institute (IFPRI) to quantify the impact of changes in agricultural yields on GDP growth. Soft linking the CGE model to household (HH) survey income data from the Integrated HH Survey (IHS2), they investigate how changes in agricultural productivity affect poverty. The IFPRI model estimated that achieving 6% growth in agricultural yields during the 2005-2015 period, would increase the overall GDP growth rate from 3.2% to 4.8% per year, leading to poverty falling to 34.5% by 2015. This was considerably lower than the 47.0% poverty rate projected in the absence of additional agricultural growth. The 6% agricultural yield growth resulted in an additional 1.88 million people being lifted out of poverty by 2015. Based on these estimates, Yaron *et al*. (2011) inferred that an annual agricultural yield reduction of 6% as a result of on-site soil erosion will lead to a total GDP being reduced by approximately 1.6% each year. It is worth noting that the studies reported above only calculated on-site impacts and do not consider the transfer of soil within the catchment. For instance, the loss of soil from upstream farmers can benefit downstream farmers.

Recently, Vargas and Omuto (2014) performed a soil loss assessment using the SLEMSA model with secondary data. They found average national soil loss rates in 2014 to be of 29 t/ha/year. The areas with relatively high rates were mostly in the north with some pockets in the southern region. The northern region had soil loss rates ranging between 0.4 to 39 t/ha/year. Nkhata Bay district was the most affected while Rumphi was the least affected. The main contributing factors for Nkhata Bay were prevalent steep slopes, fragile soil, and high rainfall. Overall the severity of soil loss problems in Malawi in 2014 could be regarded to have been moderate in the north and light elsewhere. The severity of soil loss problems in the northern region seemed to arise from the fragile and shallow soil types, lack of good soil management practices, steep slopes, and high rainfall.

2.3 Soil conservation and nutrient replacement measures

Modern agricultural practices, associated with agricultural intensification and an increase in population, have a common objective to increase productivity without considering long-term impacts on the soil nutrients and their depletion from soils. Ricker-Gilbert *et al.* (2014) empirically verify Boserup's (1965) hypothesis that a growing population leads to increased input use per unit of land and increased production per unit of land. With population growth, farmers tend to move away from labour saving practices like slash and burn agriculture and increase labour and capital-intensive practices such as the use of inorganic fertilizer and hybrid seeds, which maximize output per unit of land. Their results seem to confirm the hypothesis stating that areas with population pressures are associated with input intensification (i.e. smaller farm sizes, lower real agricultural wage rates and higher real maize prices).

On the other hand, Sustainable Agricultural Practices (SAP) can provide many benefits and help farmers cope with the global challenges of land degradation, climate change, food insecurity and poverty. A review of Ellis-jones and Tengberg (2000) analysed the importance of the antierosion measures among the indigenous communities of sub-Sharan Africa, confirming the efficiency of these in reducing land degradation but also analysing the solutions that farmers identify to adapt the practices to changing agro-climatic conditions and shocks.

Among SAP practices, those related to Conservation Agriculture (CA) received increasing attention from the scientific community and international organizations. CA is a set of land management practices characterized by minimum tillage, permanent organic soil coverage, legume intercropping and crop diversification. The reasons to advocate CA are numerous: it has been reported to reduce soil degradation and improve yields but also profitability and income (Asfaw *et al.*, 2014; Kaluzi *et al.*, 2017). Ortega *et al.* (2016) analyse how diversifying maize monocrop with legumes would help reducing a declining soil fertility and thus the unbalance of nutrients. Ngwira *et al.* (2012) in a study conducted in Malawi found that maize with intercropping of the legume pigeonpea plus minimum tillage was more profitable than minimum tillage in continuous maize cultivation, which was in turn more profitable than conventional tillage based agriculture.

Despite the benefits of CA and the support of the government and NGOs, rates of adoption of CA in Malawi is still low. According to some recent studies, less than 2% of smallholder farmers are adopting a full set of CA practices (Phiri *et al.*, 2012; Dougill *et al.*, 2017).

3 Data

In this study we employ three sources of data to collect information suitable for the analysis of the impact of soil and nutrient loss on farmers' welfare and the capacity of SAP to mitigate such impacts.

First, socio-economic data at the HH level are included in the Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA). Second, detailed climatic data are gathered from the Africa Rainfall Climatology version (ARC2) at enumeration area (EA) detail. Moreover, information on nutrients loss (potassium, phosphorous, carbon and nitrogen) are also provided at plot level. Third, the Soil Loss Assessment in Malawi (Vargas and Omuto, 2016) provides information at both plot and EA level on measures of soil loss.

The survey LSMS-ISA is a HH survey program established with the financial help and support of the Bill and Melinda Gates Foundation and implemented by the LSMS team. In each partner country, the LSMS-ISA supports multiple rounds of a nationally representative panel survey with an approach designed to improve the understanding of the links between agriculture, socioeconomic status, and non-farm income activities. The questionnaires, which were gathered by the Development Economic Research Group of the World Bank, provide detailed information on individual agricultural activities, HH socio-economic characteristics and the community infrastructure.

The LSMSA-ISA survey has been conducted in Malawi during the 2010-2011 and the 2012-2013 seasons. The LSMS-ISA project is providing technical and financial assistance to the Malawi Integrated Household Survey (IHS) Program, starting with the Third Integrated Household Survey (IHS3) 2010/11 and the Integrated Household Panel Survey 2013, whose primary objective is to track and re-interview approximately one-quarter of the household sample that was previously interviewed as part of the IHS3.

The Malawi National Statistics Office (NSO) is the implementing agency for the IHS3 2010/11 and the IHPS 2013. In addition to the LSMS-ISA project, the IHS3 2010/11 was funded by the Government of Malawi, the Government of Norway, DFID, the Millennium Challenge Corporation, and Irish Aid. The LSMS team is the primary source of technical assistance in support of the design and implementation of the IHS3 2010/11 and the IHPS 2013.

The IHS3 sample includes 12,271 households surveyed with detailed information including at plot level. The overall sample is representative at national, regional, district and urban/rural level. 3,247 IHS3 households were designated as "panel" prior to the start of the IHS3 field work who were visited twice during the IHS3 (in the post-planting and post-harvest periods with respect to the rainy agricultural seasons) and are being tracked and re-interviewed as part of the IHPS. The IHPS was designed to be representative at the national level. The final sample is obtained by merging the LSMA-ISA survey with the Soil Loss Assessment dataset.

An additional source of socioeconomic data could be the SAPP 2014 survey implemented by the Government of Malawi with the support of IFAD and FAO. The main aim was to gather data to contribute to poverty reduction and improved food security through promotion of SAP and CA practices. This survey could be fundamental to evaluate the impact of a full set of these practices on mitigating soil and nutrient loss, but, at the present, it is not possible to merge the survey with the Soil Loss Assessment Data. This extension could be done in the next round of analysis in order to provide a much richer set of suggestions to policy maker.

Table 1: descriptive statistics (HH level)

Variable	Description	Mean	Std. Dev.	Min	Max
rexpaggcap	Real per capita expenditure (MWK)	50727.46	47727.52	2972.58	675676.90
TLU	Tropical livestock unit	0.47	1.44	0.00	31.38
tech_endow	HH is owner of communication technologies (%)	0.60	0.49	0.00	1
owner	HH is owner of the cultivated land (%)	0.79	0.41	0.00	1
n_plot	number of plots cultivated (count)	2.18	1.18	1.00	9.00
spfarm2	HH is specialized in agriculture (>75% of income from crop activities)	0.42	0.49	0.00	1
D_crop_maize	HH cultivates maize	0.97	0.17	0.00	1
D_crop_groundnut	HH cultivates groundnut (%)	0.27	0.44	0.00	1
D_crop_legume	HH cultivates legumes (%)	0.10	0.31	0.00	1
D_crop_other	HH cultivates other crops (%)	0.42	0.49	0.00	1
parliament	In the community resides a parliament member (%)	0.11	0.31	0.00	1
infraindex	index of access to infrastructure	-0.02	0.88	-1.30	11.67
wealth	wealth index	0.23	1.34	-0.71	12.85
N	Number of households (HH)	7376			

Climatic and weather data are based on the ARC2, an improved version of the ARC1, which combines inputs from two sources: i) 3-hourly geostationary infrared (IR) data centred on Africa from the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and ii) quality controlled Global Telecommunication System (GTS) gauge observations reporting 24-h rainfall and temperature in Africa with Historical rainfall data from 1983-2014 on a decadal basis. For further details, see Novella and Thiaw (2013). These data allow for calculating the standardized precipitation evapotranspiration index (SPEI). The SPEI is a state-of-the-art indicator in climatic science, which allows to determine onset, duration and magnitude of drought conditions with respect to normal conditions. The index is able to capture both short-term and long-term anomalies depending on the time scale over which it is calculated. Using historical precipitation and temperature data, it is possible to calculate the SPEI on a six-month basis to precisely map the seasonal pattern averaged over enumeration areas. This index presents some advantages over other indicators. It is based on the probability of recording a given amount of evapotranspiration. The probability is standardized, with a value of zero indicating the median amount (half of the historical amounts are below the median, and half are above the median), thus the index is negative for drought, and positive for wet conditions. The characteristic of being standardized provides a straightforward interpretation and allows for a fully indexed comparison through time and space.

The last data source is the recent Soil Loss Assesment in Malawi (2016) published by FAO, UNEP, UNDP and MAIWD. This assessment includes information at both EA and plot level on soil loss. Together with soil loss, the assessment provides precious information on nutrient loss (phosphorous, potassium, nitrogen and carbon). Both measures are expressed in tons per hectare in 2011 and 2013.

All the data sources described here are merged at EA, HH and plot area level so as to allow for a complete cross-sectional dataset rich in economic, social, agronomic and climatic information, and for an in-depth micro and local analysis. Complete descriptive statistics for selected variables at HH level are presented in Table 1, while Table 2 presents statistics for variables at plot level. These variables are selected according to our aim, literature and the data availability limitations.

Table 2: descriptive statistics (plot level)

Variable	Description	Mean	Std. dev.	Min	Max
Dep. variable					
Maize_kg	Total production of maize (kg)	470.37	480.71	0.16	5862.08
Soil loss measure					
soil_loss	Soil loss per ha (kg/ha)	15248.60	8256.81	242.00	39895.00
Nutrients loss					
P	Phosphorous loss per ha (grams/ha)	39.58	44.47	0.65	319.65
N	Nitrogen loss per ha (grams/ha)	3955.35	6990.15	15.00	47845.62
OC	Carbon loss per ha (grams/ha)	1039.87	837.13	3.42	4179.10

K	Potassium loss per ha (grams/ha)	106.18	115.37	0.00	740.00
HH characteristics					
agehead	Age of HH head (years)	43.92	16.20	15.00	110.00
femhead	Female headed HH (%)	0.24	0.43	0.00	1.00
educave	Ave. no. of school years of HH members aged 15-60	5.21	2.69	0.00	18.50
hhsize	Number of HH members (count)	5.03	2.32	1.00	20.00
disturban	Distance of HH from the main urban center (Km)	113.72	107.31	0.00	1200.00
plot_area	Area of cultivated plot (ha)	0.43	0.40	0.00	20.23
Production inputs					
labor	Men days of labor on plot	50.06	37.62	0.00	280.00
fert1	Chitowe (Kg)	37.85	34.21	0.00	300.00
fert2	Urea (Kg)	30.89	30.07	0.00	250.00
fert3	Compound (Kg)	3.84	16.05	0.00	200.00
fert4	Other fertilizers (Kg)	1.47	11.21	0.00	450.00
organic_fert	Organic fertilizer (Kg)	108.62	758.60	0.00	25000.00
pesticides	Pesticides (Kg)	0.06	2.91	0.00	250.00
seeds	Seeds amount (Kg)	8.62	7.36	0.00	100.00
Agricultural controls					
MV	Modern Variety Seed (%)	0.52	0.50	0.00	1
groundnut	Mixed cropping with groundnut on plot (%)	0.07	0.26	0.00	1
other_crops	Mixed cropping with other crops on plot (%)	0.24	0.43	0.00	1
legumes	Mixed cropping with legumes on plot (%)	0.08	0.27	0.00	1
Climate controls					
s_r_spei	Rainfall shock experienced (%)	0.38	0.49	0.00	1
s_d_spei	Drought shock experienced (%)	0.46	0.50	0.00	1
Geographical controls					

aez1	Tropic -Warm/Semiarid (%)	0.41	0.49	0.00	1
aez2	Tropic-Warm/Subhumid (%)	0.36	0.48	0.00	1
aez3	Tropic-Cool/Semiarid (%)	0.10	0.31	0.00	1
aez4	Tropic-Cool/Subhumid (%)	0.12	0.33	0.00	1
Time controls					
2013	Year of survey	0.22	0.41	0.00	1
N	**Number of plots**	**9255**			

Table 3 reports the percentage of adoption of four agricultural practices that we will use to assess their impact on mitigating the nutrient and the soil loss together with the application rates of fertilizers. These includes an index of crop diversification[1], adoption of antierosion measures, adoption of nitrogen fixing mixed cropping (legumes) and leaving the land fallow for at least one year over the span of five years.

Table 3: descriptive statistics of agricultural practices (plot level)

Variable	Description	%
S_HH_class	Shannon index	
1	monocropping of maize	52
2	low diversification (2<Shannon<3)	27
3	medium-low diversification (2<Shannon<3)	12
4	medium-high diversification (3<Shannon<4)	5
5	high diversification (Shannon>5)	4
Antierosion	Antierosion measures	
No erosion		62
Terraces		3

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[1] The Shannon diversity index is calculated as: $H_j = -\sum_{c=1}^{C} p_c \ln p_c$, where p_c is the proportion of area cultivated with crop c on the total cultivated area of the farmer j. The Shannon index measures the uncertainty to predict the species identity of an individual that is randomly taken from a community. The higher the Shannon index, the higher the uncertainty and consequently the evenness in the dataset is lower. The use of the Shannon index in measuring the different components of agricultural biodiversity is diffused in literature (Mader *et al.*, 2002; Di Falco and Perrings, 2005; Mouysset *et al.*, 2012; Coromaldi *et al.*, 2015; Pallante *et al.* 2016; Asfaw *et al.*, 2018). For a complete review of the diversity indicators, with all the pros and cons of each measurement, see Duelli and Obrist (2003).

bunds		29
Vetiver grass		5
Tree belts		1
D_crop_legume	Mixed cropping maize-legumes	
No legumes		90
Yes legumes		10
Fallow	at least 1 year of fallow in the past 5 years	
no fallow		86
yes fallow		14

4 Methodology

Detailed technical information on the methodology adopted are reported in Appendix A. For the sake of brevity, it is worth mentioning that we estimated the impact of soil and nutrient loss on the production function of maize. Maize was selected because is the most cultivated crop in Malawi. The production function accounts for all the inputs, other crops cultivated on the plot and the area cultivated so as to implicitly facilitate the generalization of results from the effect on total production to the productivity (yield). A quantile model is used for estimation, which allows the results to be interpreted in terms of the population. Moreover, the quantile model is also suitable for catching potential non-linear effects of the impact of soil and nutrient loss on, for instance, the less productive farmers or the poorest ones. The same methodology is applied to evaluate the impact of soil and nutrient loss on broader measures of welfare, such as the total per capita consumption and the caloric intake. All the estimations are completed with interaction and squared terms that allow to discern the marginal effects (ME) of an increase in soil and nutrient loss when the HH is female headed or when it is in certain agroecological zones or districts.

The results of these econometric estimations have to be interpreted as elasticities. That is, for a 1% increase in the soil or nutrient loss to all the HHs in the sample, with respect the current average, there is a X% variation of the maize production (or consumption and caloric intake).

These elasticities are then used to obtain a difference in the production value of maize caused by hypothetical and most severe scenarios (+10%, 25% and 50%) of soil and nutrient loss at the national level and expressing these differences in monetary terms (using the unit value of maize) in order to obtain the aggregate loss at the national level both in terms of GDP and agricultural production value.

The elasticities also enter a computable general equilibrium (CGE) model as exogenous shock to the agricultural production function. The advantage of carrying out a general equilibrium analysis is substantial, as several feedback effects are captured by the model. Indeed, econometric analysis based on the partial equilibrium setting does not allow for the evaluation of the effects of soil loss that spread over the sector analysed, that is maize production and related impacts of the welfare variables employed here (total HH consumption and caloric intake). The CGE analysis captures potential impacts deriving from the productivity loss given by the soil change. For instance, if more fertilizers are required to compensate for soil degradation, it is worth analysing whether and to what extent additional demand for these inputs impacts the import sector and the domestic production of specific inputs, as well as the Malawian economy as a whole. The technical details of the "linkage" between the micro-econometric and the CGE analyses, and how this approach is operationalized, are provided in the Appendix A4.

In order to estimate the mitigation impact of agricultural practices we first select the practices on the basis of their efficiency in reducing the soil and nutrient loss. For this aim we implement an endogenous switching regression (ESR) that has the advantage to provide counterfactual scenarios of the impact of adopting a practice as opposed to not adopting it, and a SUR estimation which account for complementarities among nutrients. Technical details on these models are available in the Appendices A2 and A3. After the selection, we re-estimate the production function by linking the practices with the soil and nutrient loss, thus obtaining new elasticities of adopting a practice as opposed to not adopting it.

5 Impact of soil loss at the micro level

5.1 Impact of soil loss on agricultural production

Table 4 shows the impact of soil loss on maize production for deciles of the total production distribution. Estimations are obtained at the plot level and clustered at the HH level with both outcome and independent variables expressed in logarithms.

The reduction impact (elasticity) of soil loss on maize production ranges from -0.139 to -0.269 percent, with lower values corresponding to higher deciles. The average value of soil loss impact is -0.228 percent.

Other than standard inputs of the production function (labour, fertilizers, area of cultivated land, human capital via education, etc.), whose coefficient signs and magnitudes are in line with the agro-economical literature, we assess the impact of soil loss by also controlling for a vector of agro-ecological characteristics that may affect the productivity and for year fixed effects. Moreover, we include controls for drought and rainfall shocks as represented by the six-month SPEIs larger than 1.5 s.d. (in absolute value), which is statistically relevant in explaining a reduction in productivity in the case of negative SPEI values (drought). The effects are always significant and decreasing as deciles capture higher sections of the maize production distribution.

Other agro-ecological determinants are included in the analysis by means of dummies of the agro-ecological zones interacted with the soil loss variable (not shown in Table 4). The marginal effects of soil loss on maize yield are presented in Figure 1, by keeping into account the interaction between soil loss and the agro-ecological zones. Confidence intervals are also illustrated. With the exception of tropic-cool/subhumid agroecological zones in which these effects are not significant, the impact on the other agroecological zones are negative and significant, with stronger effects on semiarid agroecological zones.

Table 4: Effect of soil loss on maize production (kg), by decile

	Deciles								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
agehead	0.001	0.001	0.001	0.001	0.001	0.002***	0.002***	0.002***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
female headed hh	-0.926*	-0.819***	-0.863**	-0.824***	-0.374	-0.156	-0.093	-0.290	0.005
	(0.513)	(0.488)	(0.355)	(0.302)	(0.392)	(0.262)	(0.271)	(0.265)	(0.364)
educave	0.038***	0.038***	0.032***	0.030***	0.033***	0.032***	0.035***	0.037***	0.036***
	(0.009)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
hhsize	0.003	0.009	0.009	0.016***	0.019***	0.017***	0.017***	0.019***	0.021***
	(0.008)	(0.006)	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)	(0.005)	(0.006)
disturban	-0.015	-0.008	-0.013	-0.016*	-0.022***	-0.021***	-0.020***	-0.015*	-0.017**
	(0.016)	(0.010)	(0.009)	(0.008)	(0.007)	(0.008)	(0.007)	(0.008)	(0.008)
plot_area	0.310***	0.300***	0.289***	0.300***	0.317***	0.331***	0.319***	0.334***	0.331***
	(0.025)	(0.020)	(0.021)	(0.019)	(0.018)	(0.018)	(0.016)	(0.017)	(0.019)
labor	0.132***	0.115***	0.103***	0.090***	0.091***	0.087***	0.073***	0.075***	0.064***
	(0.025)	(0.018)	(0.015)	(0.014)	(0.013)	(0.013)	(0.015)	(0.012)	(0.016)
fert1	0.118***	0.113***	0.114***	0.114***	0.100***	0.093***	0.095***	0.086***	0.074***
	(0.011)	(0.008)	(0.006)	(0.006)	(0.005)	(0.005)	(0.006)	(0.005)	(0.007)
fert2	0.125***	0.114***	0.111***	0.102***	0.096***	0.093***	0.091***	0.084***	0.074***
	(0.013)	(0.008)	(0.006)	(0.006)	(0.006)	(0.005)	(0.006)	(0.005)	(0.006)
fert3	0.070***	0.064***	0.075***	0.082***	0.089***	0.094***	0.081***	0.077***	0.075***
	(0.021)	(0.020)	(0.014)	(0.013)	(0.012)	(0.011)	(0.012)	(0.012)	(0.014)
fert4	0.092*	0.081***	0.092***	0.091***	0.082***	0.068***	0.058***	0.075***	0.083***
	(0.055)	(0.019)	(0.021)	(0.017)	(0.013)	(0.013)	(0.022)	(0.017)	(0.030)
organic_fert	0.029***	0.016**	0.020***	0.017***	0.019***	0.023***	0.027***	0.031***	0.028***
	(0.009)	(0.006)	(0.007)	(0.005)	(0.005)	(0.005)	(0.007)	(0.006)	(0.006)
pesticides	-0.221	0.117**	0.062	0.143	0.136**	0.129	0.173***	0.126***	0.121
	(0.411)	(0.047)	(0.061)	(0.173)	(0.056)	(0.094)	(0.036)	(0.027)	(0.209)
seeds	0.197***	0.174***	0.186***	0.177***	0.181***	0.188***	0.187***	0.187***	0.162***
	(0.029)	(0.020)	(0.018)	(0.017)	(0.014)	(0.015)	(0.016)	(0.016)	(0.017)

MV	0.039	0.054*	0.084***	0.070***	0.082***	0.096***	0.117***	0.107***	0.101***
	(0.039)	(0.028)	(0.025)	(0.022)	(0.020)	(0.019)	(0.022)	(0.021)	(0.024)
ground-nut	-0.134	-0.136***	-0.084	-0.071*	-0.061*	-0.082**	-0.092**	-0.078*	-0.078*
	(0.083)	(0.045)	(0.052)	(0.041)	(0.036)	(0.035)	(0.039)	(0.044)	(0.046)
other_ crops	-0.120**	-0.099***	-0.114***	-0.123***	-0.120***	-0.106***	-0.089***	-0.081***	-0.106***
	(0.048)	(0.036)	(0.027)	(0.024)	(0.024)	(0.023)	(0.025)	(0.024)	(0.029)
beans	0.192***	0.187***	0.123***	0.106***	0.107***	0.131***	0.088***	0.062*	0.074
	(0.074)	(0.047)	(0.035)	(0.038)	(0.035)	(0.033)	(0.034)	(0.032)	(0.052)
s_r_spei	0.099**	0.137***	0.104***	0.101***	0.088***	0.092***	0.084***	0.101***	0.080***
	(0.050)	(0.041)	(0.030)	(0.029)	(0.025)	(0.027)	(0.029)	(0.027)	(0.030)
s_d_spei	-0.426***	-0.358***	-0.311***	-0.300***	-0.254***	-0.228***	-0.205***	-0.196***	-0.184***
	(0.055)	(0.035)	(0.028)	(0.029)	(0.026)	(0.025)	(0.028)	(0.025)	(0.031)
soil_loss	**-0.269*****	**-0.258*****	**-0.263*****	**-0.246*****	**-0.249*****	**-0.223*****	**-0.208*****	**-0.195*****	**-0.139*****
	(0.047)	(0.053)	(0.034)	(0.031)	(0.029)	(0.022)	(0.031)	(0.033)	(0.026)
soil_ loss:fem-head	-0.097*	-0.055	-0.078**	-0.074**	-0.031	-0.006	-0.002	-0.018	-0.018
	(0.057)	(0.051)	(0.037)	(0.032)	(0.041)	(0.028)	(0.029)	(0.028)	(0.039)
Constant	6.052***	6.444***	6.840***	6.981***	7.218***	7.153***	7.208***	7.279***	7.219***
	(0.458)	(0.510)	(0.326)	(0.303)	(0.282)	(0.217)	(0.303)	(0.316)	(0.252)
N	9255								

Notes: Standard errors clustered at EA level are in parentheses, * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Estimates include dummies for agroecological zones and districts, interactions of agroecological zones and districts with the soil loss measure and year 2013.

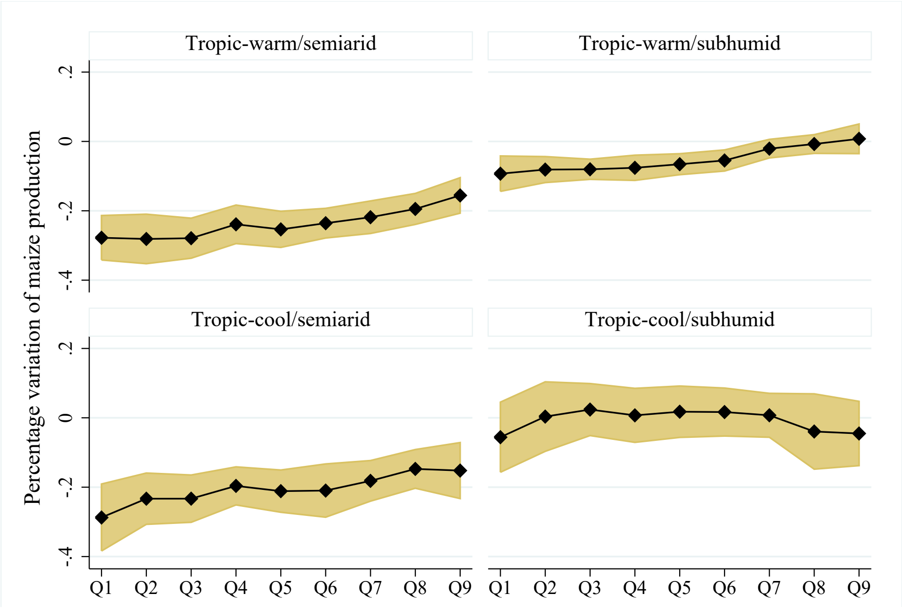

Figure 1: Elasticity, percentage variation of maize production for a 1% increase in soil loss, by agroecological zone

5.1.1 Scenarios of soil loss at district level

In order to provide evidence at a more detailed spatial level, we also estimate the impacts of soil loss at the district level in terms of maize productivity and assuming two different loss scenarios. The first baseline scenario assumes an average of 10 tons/hectare loss in each district.

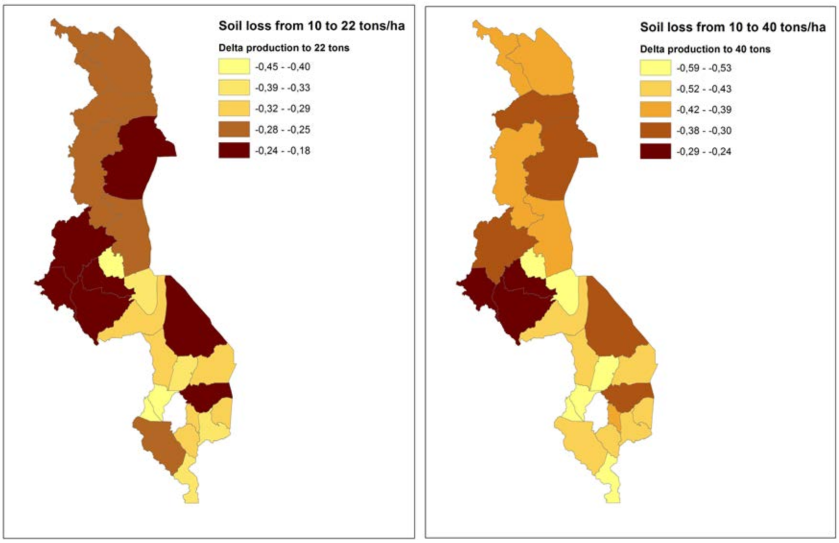

Figure 2 - Expected delta maize productivity for 22 tons/ha (left) and 40 tons/ha (right) in % w.r.t. a baseline scenario of 10 kg/ha

These two comparison scenarios assume, respectively, an average loss of 22 (Moderate Loss Scenario) and 40 (Severe Loss Scenario) tons/hectare in each district, considering that the national average soil loss is about 15 tons/hectare, with peak values of about 41 tons/hectare. We obtain these numbers by estimating a different elasticity for each district of Malawi. The results are presented in Figure 2, which shows the impacts based on percentage changes in maize production relative to the baseline scenario. For instance, a 10% change has to be interpreted as a 10% reduction in the total maize production (expected impact) if that district would have an average soil loss of 22 tons/hectare instead of 10. The same interpretation applies when we compare the baseline scenario with the 40 tons/hectare scenario.

The analysis by district shows that the largest expected impacts affect the southern districts, in all the three comparisons. When assuming the 10 tons/hectare as the baseline scenario, an average loss of 22 tons/hectare yields expected impacts of 32-61% of loss in maize productivity. When imposing a severe scenario with an average loss of 40 tons/hectare, the expected productivity loss ranges from 39% to 77% with regard to the baseline. Finally, when assuming the moderate scenario of 22 tons/hectare as a baseline and comparing it with the severe scenario of 40 tons/hectare, the expected loss in maize productivity ranges from about 9% to 44%.

Table 5 reports the delta productivity expressed in kg/hectare for the two scenarios, assuming as a baseline a value of 10 tons/hectare.

Table 5: Expected delta productivity by district (kg/ha) of moderate and severe scenarios of soil loss with respect to a baseline of 10 kg/ha

District	Expected delta productivity	
	Moderate (22 tons/ha)	Severe (40 tons/ha)
Balaka	-734	-1192
Blantyre City	-576	-808
Blanytyre	-640	-919
Chikwawa	-492	-814
Chiradzulu	-586	-834
Chitipa	-623	-907
Dedza	-668	-967
Dowa	-518	-706
Karonga	-625	-909
Kasungu	-565	-801
Lilongwe	-523	-708
Lilongwe City	-948	-1378
Machinga	-643	-927
Mangochi	-522	-714
Mchinji	-483	-638
Mulanje	-615	-882
Mwanza	-941	-1339
Mzimba	-644	-939
Mzuzu City	-450	-555
Neno	-1078	-1368
Nkhatabay	-492	-665
Nkhota kota	-633	-922
Nsanje	-946	-1448
Ntcheu	-739	-1086
Ntchisi	-1090	-1577
Phalombe	-608	-872
Rumphi	-596	-856
Salima	-854	-1239
Thyolo	-642	-931
Zomba	-454	-582
Zomba City	-609	-870

5.2 Impacts of soil loss on broad measures of welfare: consumption and caloric intake per capita

Table 6 reports the effect of soil loss on the annual per capita consumption expressed in constant 2010 MWK and per capita caloric intake (cal/pc/day). This latter is as assumed as a proxy of food security and calculated using the information available in the LSMS-ISA.

Table 6: Soil loss impact on consumption and food security

	Deciles								
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
soil_loss impact on consumption	-0.103**	-0.111*	-0.105*	-0.103*	-0.104*	-0.086	-0.075	0.062	0.046
	(0.052)	(0.068)	(0.065)	(0.055)	(0.056)	(0.075)	(0.075)	(0.076)	(0.069)
soil_loss impact on food security	-0.143*	-0.125**	-0.119**	-0.115*	-0.114**	-0.105*	-0.084	-0.068	-0.052
	(0.067)	(0.062)	(0.060)	(0.065)	(0.061)	(0.052)	(0.067)	(0.043)	(0.049)
N	7376								

Notes: Standard errors clustered EA level are in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01. Estimates include dummies for Aagroecological zones, interactions of agroecological zones with the nutrient loss measures and year 2013.

The full estimation tables are reported in the Appendices B2 and B3. Estimates are obtained at the HH level with all variables expressed in logarithms. With respect to the specification followed in the production function, we focus on socio-economic characteristics that may affect the HHs' expenditure and food security.

The impact of soil loss on the total HH consumption is concentrated along the lower consumption deciles, which show a negative and significant coefficient. This could be justified by the fact that poorer farmers have lower access to other income sources and are thus strictly dependent on agricultural and agro-ecological conditions. This interpretation is also confirmed by the coefficients of SPEI, which are negative drivers of per capita consumption level only for lower deciles. The impact of soil loss on consumption in the first four deciles ranges from -0.025 to -0.032 percent. On the contrary, higher quantiles are not significantly affected by soil loss, given that wealthier HHs can rely on other sources of income other than agriculture.

The lower part of Table 6 shows the percentage impact of a 1% soil loss on the per capita caloric intake. These results point to a significant and negative effect of soil loss on the quantity of calories available, with the largest magnitude of elasticity in the first decile and decreasing effects up to the sixth decile that can be explained in the same way as for the consumption.

The full estimation tables are reported in the Appendices B2 and B3. Estimates are obtained at the HH level with all variables expressed in logarithms. With respect to the specification followed in the production function, we focus on socio-economic characteristics that may affect the HHs' expenditure and the food security.

5.3 Summary of the effects of soil loss

Figure 3 summarizes the impacts of soil loss by representing the elasticity values for maize production, total consumption and food security (caloric intake) obtained from the different econometric models by reporting only the deciles with outcomes statistically significant at 10% level ($p \leq 0.10$). The horizontal axis shows the impacts on the three dimensions analyzed in terms of percentage changes given a 1% change in the soil loss.

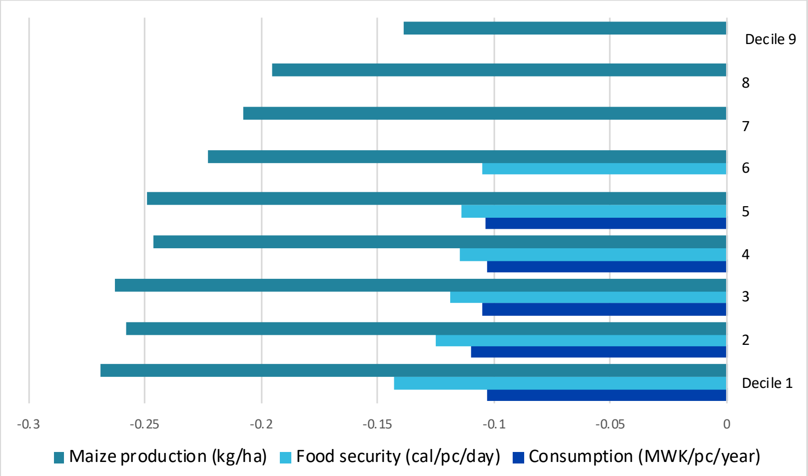

Figure 3 - Impacts of soil loss by representing the elasticity values for maize production, total consumption and food security

The most severe impacts of soil loss affect maize production, with elasticity values much higher than the ones found for food security and consumption. It is important to highlight that the largest and most significant effects are concentrated along the lower deciles of the outcome distributions, on the most fragile sectors of the population. This pattern is consistent for all three outcomes.

5.4 Impact of soil loss and nutrient loss by gender

In all the estimations described above, we included a term that indicated whether the HH is headed by a female. Moreover, we tested the hypothesis that a female headed HH is more greatly impacted by soil loss, in terms of productivity and welfare measures, by integrating the dummy femhead with the soil loss. Elasticities can be observed in the Appendix B1, B2 and B3. In Figure 4: Percentage impact of 1% soil loss increase on per capita consumption and maize productivity, by gender, we illustrate the percentage change of the productivity and per capita consumption (not significant impact on caloric intake) by gender for a 1% increase in the soil loss. It is straightforward to note that for both the indicators the negative impact of soil loss is more than double that of a male headed HH. This result confirms that the female headed HH are the most fragile group and the impact of erosion could affect them more severely.

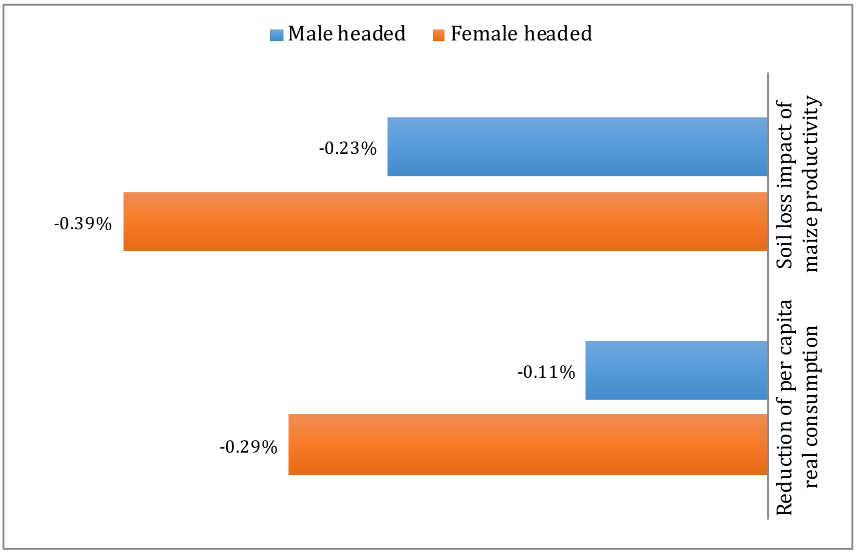

Figure 4: Percentage impact of 1% soil loss increase on per capita consumption and maize productivity, by gender of HH head

6 Impact of nutrient loss at the micro level

The majority of soil in Malawi are generally loamy sands that are moderately acidic (Snapp, 1998). Long-term use of fertilizer (and especially acidic ones) can significantly affect the pH status of these soils and eventually impact the production of pH-sensitive crops such as maize. Studies on fertilizer use in Malawi show that the dominant fertilizers are Urea, 23:21:0+4S (Chitowe), CAN, and D compound (GoM) since they are subsidized through the FISP. Urea and NPK 23:21:0+4S (Chitowe) are commonly applied to maize, whereas CAN and D compound suit tobacco production despite farmers applying them also to other crops. Chitowe is a balanced P source that is particularly appropriate for maize grown in mixtures or rotations with legumes, as the P will have residual benefits for legumes. It is also appropriate for acidic soils in which it is unavailable due to fixation.

The effects of nutrient loss on maize production are presented in the Appendix B1 together with the full set of proximate and underlying drivers of covariates. It is worth mentioning that we consider nutrient loss both separately and with interactions terms among the four loss measures to account for interaction effects among nutrients.

In Figure 4, 6 and 7, we illustrate the estimated maize productivity according to increases in nutrient loss by agro-ecological zones. Only the significant effects are illustrated, in which some interesting results are reported. First, the delta economic unit value of the change in productivity is a first indicator of the economic impact caused by the nutrient loss.

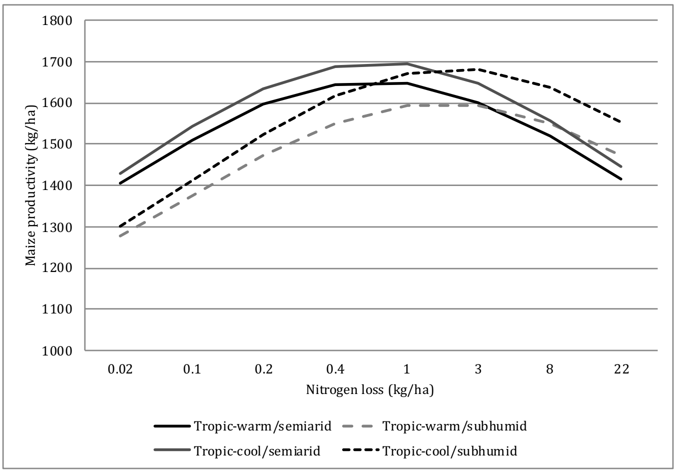

Figure 5: Expected impact of N loss on maize productivity (linear prediction), by agroecological zone

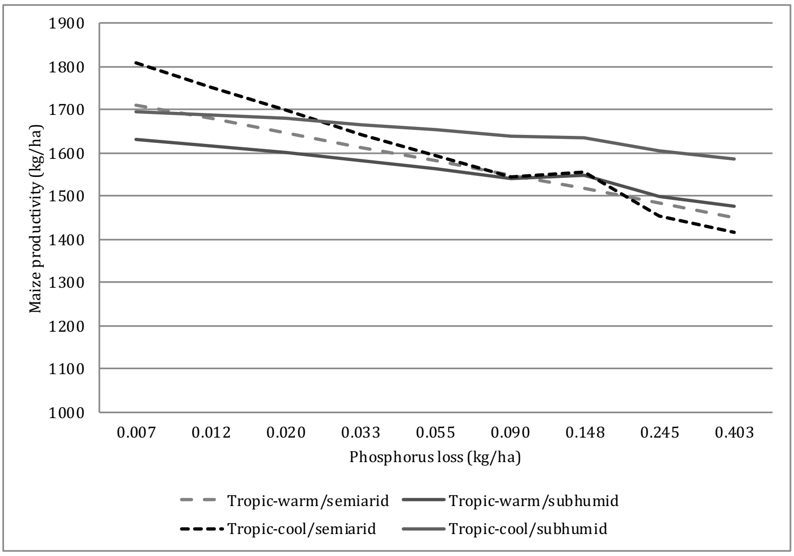

Figure 6: Expected impact of P loss on maize productivity (linear prediction), by agroecological zone

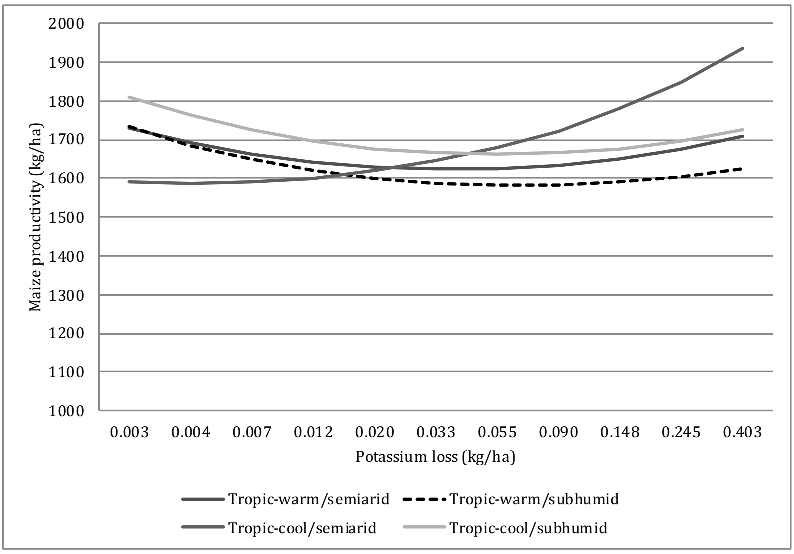

Figure 7: Expected impact of K loss on maize productivity (linear prediction) , by agroecological zone.

Second, the impact of nitrogen loss is not linear. The estimation in the Appendix reports a negative and significant effect of nitrogen loss on maize production, with slightly stronger effects on lower deciles of the population. In fact, the impact of 1% of nitrogen loss increase on maize production ranges from -0.15 to -0.34 percent. As a consequence, the most fragile rural HHs are affected twice as much as wealthier farmers.

Figure 5 shows that for very small quantities of loss we see an increase in productivity since the loss is negligible from an agronomic point of view. For an interval between 1 and 4 kg/ha of N loss (according to the agroecological zone) we see that the loss of nitrogen severely impacts maize productivity with high variation observed in semiarid agro-ecological zones.

Third, while the loss of phosphorus always shows a negative impact on maize productivity (with higher effects, again, in the semiarid region), the loss of potassium over a certain threshold does not show a clear negative impact, with the exception of the tropic cool semiarid regions where the loss has positive effects. This result seems to point out a likely excess of this nutrient in the soils.

Fourth, the semiarid regions are the ones most affected by the loss of nutrients.

Regarding the results of interaction effects estimation between nutrients loss, Figure 8 illustrates the trend of maize productivity for increasing levels of N loss when the latter is simultaneously combined with the loss of P. The Figure shows that for an increase in N loss and a low P loss (0.003 kg/ha) the maize productivity reaches a maximum of 2250 kg/ha (for around 1 kg/ha of loss), which is reduced to 2150 for a high P loss (0.4 kg/ha) and a moderate N loss (8 kg/ha).

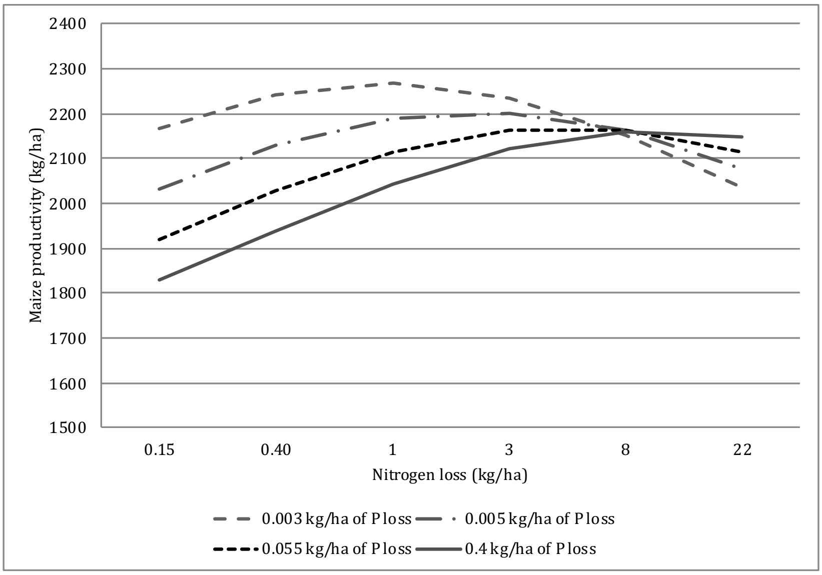

Figure 8: expected impact of nitrogen loss on maize productivity, by different levels of phosphorus loss

7 Economic implications of soil and nutrient loss at the national level

In this section, the national impact of soil and nutrient loss is estimated and expressed in terms of the total agricultural production value and the GDP. Two main shortcomings have to be considered in interpreting these results. First, the impacts are not based on a general equilibrium analysis, and they therefore do not account for potential market and demand adjustments existing between the agricultural and other sectors that are likely to arise when the first becomes less productive because of the loss. Second, the impacts are based on the reduction in maize productivity due to the soil loss and not the impact on areas where other crops other than maize are cultivated. However, it is worth noting that the maize production represents the main targeted crops in terms of agricultural policies. As a consequence of these two limitations, the national impacts must be intended as a lower bound in this partial equilibrium analysis.

7.1 Impact of soil loss in terms of GDP and agricultural production value

To estimate the impact of soil loss at the national level we use the average elasticity, obtained in Table 4, between soil loss and maize production (which indicates the reduction of production as a percentage given for a 1% increase in soil loss) by multiplying the latter, to obtain the total maize production value at the national data according to FAOSTAT data. This number represents the average reduction in maize production value deriving from a 1% increase in soil loss in all land where maize is cultivated. The ratio between the delta production value and the total agricultural production value, or between the delta production value and the GDP, allows to evaluate the magnitude of the monetary losses caused by soil loss in terms of the two macroeconomic variables.

The national values employed to estimate macroeconomic impacts are reported in the upper part of Table 7, together with the average elasticity obtained in Table 4: Effect of soil loss on maize production (kg), by decile. It is shown in the lower part that a 1% increase in soil loss is equivalent to a monetary loss, at the national level, of about 0.026% of the GDP, or the 0.420% of the agricultural production value.

Table 7: Macroeconomic variables and national impact of soil loss for a 1% increase in soil loss

	Variable	Unit	Value (ave. 2011-2013)
A	GDP	USD Mln 2005	5678.71
B	Gross production value agriculture	USD Mln 2004-2006	3429.2
C	Gross production value maize	USD Mln 2004-2006	646.73
D	Average Elasticity (% reduction of production for 1% increase in soil loss)		0.225
E	Impact of soil loss in terms of GDP = (D*C)/A	%	-0.26%
F	Impact of soil loss in terms of agricultural production value = (D*C)/B	%	-0.42%

For a more extensive interpretation of the national impacts, we provide a comparison exercise based on three different soil loss increase scenarios, different from the negligible effect of a 1% increase.

These soil loss scenarios assume incremental soil loss with respect to the current national average. The expected macroeconomic impacts in terms of GDP and total agricultural production value are reported in Figure 8. A 10% increase in soil loss would lead to monetary losses of about 0.26% of Malawian GDP and 0.42% of the total agricultural production value. Higher soil loss values produce larger impacts: in the second scenario, a 25% increase in soil loss would lead to monetary impacts of about 0.64% of the GDP and about 1% of agriculture production while, in the worst scenario, a 50% increase in soil loss yields monetary losses corresponding to about 1.28% of GDP and 2.1% of the total agricultural production value.

As a comparison, Bishop (1995) found an annual loss of 2.4%-7.7% of agricultural GDP, Nakhumwa (2004), using a nutrient replacement cost methodology, estimated a reduction of 14% of agricultural GDP and Yaron *et al.* (2011) estimated a reduction of 1.6% of total GDP in 2007. Given the different methodology employed in this work, our estimates are not directly comparable, but nevertheless fall within the range of values found in the literature.

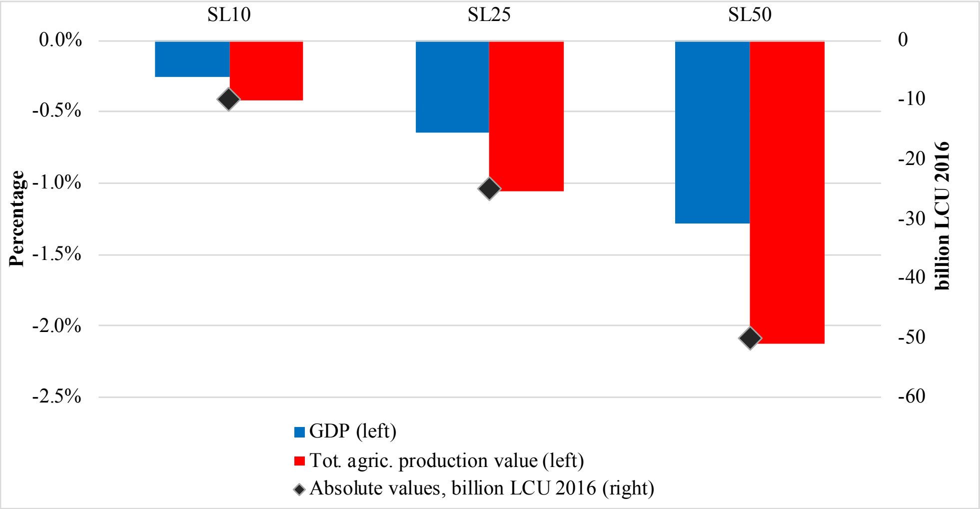

Figure 9: Expected macroeconomic monetary impacts (%) of soil loss according to different scenarios

7.2 Impact on poverty

We measure the impact on individual poverty caused by an increase in soil loss by measuring the variation in crop profits generated by reductions in maize productivity shown in Table 4. The changes in profits are thus subtracted by the total HH income per capita and per day, and transformed into dollars in order to obtain the percentage of individuals moving below the poverty line of $1.9. Table 8 reports the current percentage of population and the number of individuals who live with less than $1.9 dollar per day. In the lower part of the table, we notice a worsening of the current situation caused by the increase in soil loss. In the worst scenario, Malawi faces having an additional half a million individuals in poverty.

Table 8: Variation in the percentage of population below the poverty line caused by an increase in soil loss

Rural Poverty	Poverty headcount ratio at $1.9 a day	Number of Individuals in poverty
Current soil loss conditions	71.40% Delta Poverty headcount ratio	12,916,974 Additional individuals in poverty
Soil loss +10%	+1.5%	+271,365
Soil loss +25%	+2.1%	+379,911
Soil loss +50%	+3.1%	+560,821

7.3 Impact of nutrient loss on GDP and agricultural production value

The monetary loss, in terms of GDP and total agricultural production value, at different values of nutrient loss is illustrated in Figure 10 (N loss), 11 (P) and 12 (K). This analysis is necessary in order to discern potential non-linear dynamics between nutrient and production loss, the latter being presented in terms of percent changes of macroeconomic indicators. The analysis for carbon is not presented since the results are not statistically significant.

Figure 10 shows the monetary impacts of different levels of N loss. If the loss was moderate (e.g, 1 kg/ha) on average at national level, the maize production would account for 3.9% of GDP and 6.2% of the national agricultural value. For a high N loss (22 kg/ha) these values change to 2.7% and 4.4% respectively, indicating a reduction of around 1.2 percentage points in GDP and 1.8 percentage points of the agricultural production value.

The physical losses associated with the two other nutrients translate into additional variations of the value of maize production relative to the GDP and the agricultural production value. The impact in terms of macroeconomic variables is linear with the increase in P loss (shifting from a national average of 0.5 kg/ha to 1 kg/ha costs about 0.1% loss of GDP and 0.3% of the agricultural production value), while it shows a convex pattern in the case of K loss.

By combining all the reductions deriving from switching from the current nutrient loss conditions to a severe one scenario, and summing up these effects for all nutrients, we predict a GDP reduction of about 1.6% and a reduction of the agricultural production value of about 3.4% .

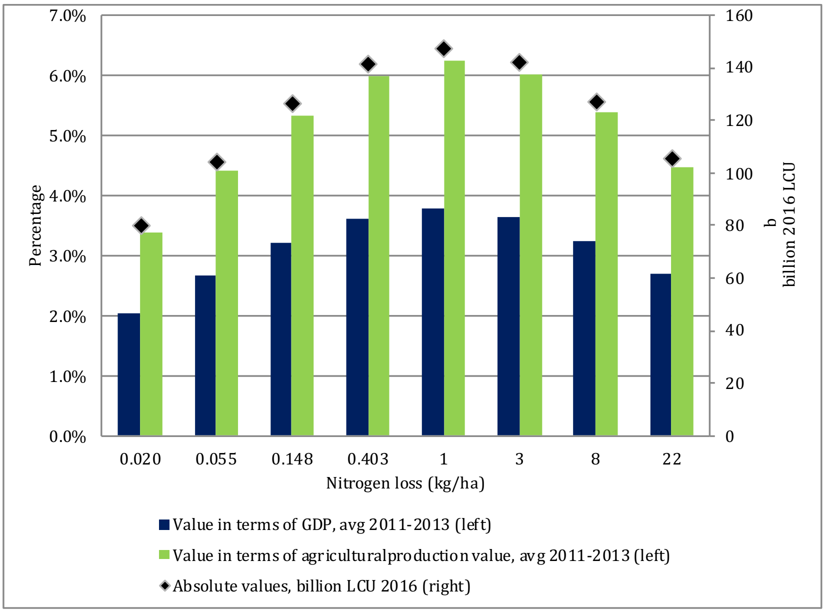

Figure 10: Value of maize production on macroeconomic indicators for different rates of nitrogen loss

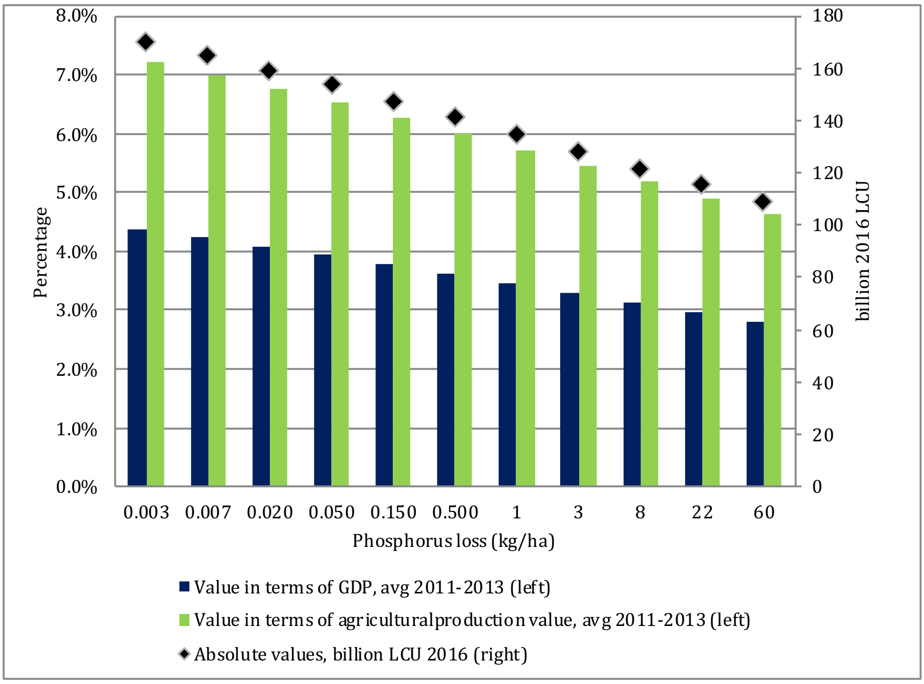

Figure 11: Value of maize production on macroeconomic indicators for different rates of phosphorus loss

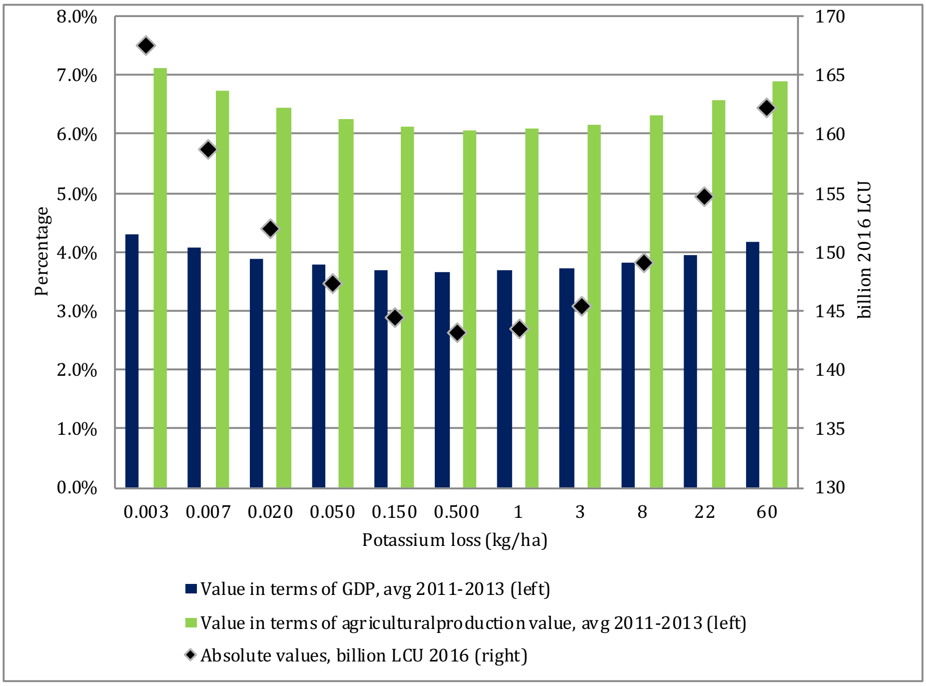

Figure 12: Value of maize production on macroeconomic indicators for different rates of potassium loss

8 Mitigation impact of agricultural practices

8.1 Selection of a set of practices

In order to identify which agricultural practices can effectively contribute to mitigating the negative impacts of soil and nutrient loss on the agricultural production, we first assess how the adoption of different practices influences the rate of soil and nutrient loss. To this aim, we focus on the main determinants of anti-erosion measures and other practices such as crop diversification and legume intercropping. Results from the ESR model (Appendix B4, additional results available upon request), show that being a plot owner or having access to information technology such as radio or television increases the chances of implementing anti-erosion measures and sustainable agricultural practices. On the contrary, HHs with female head are less likely to adopt anti-erosion measures but are more likely to practice crop diversification and legume intercropping.

Table 9 reports the treatment effects for adopting two major agricultural practices for which there are sufficient information in the dataset. The practice considered is the adoption of anti-erosion measures and their impact on soil loss (estimation in the Appendix B4).

Anti-erosion interventions are evaluated by aggregating different measures (terraces, bunds, vetiver grass and tree belts) in a single dummy variable if a HH adopts at least one of these measures. As discussed in Appendix A3, the ESR model allows to evaluate the effect of these practices in a causal empirical framework, by providing counterfactual outcomes for both adopting and non-adopting groups. The results in Table 9 represent ATEs and are expressed in kg of soil loss per hectare. Therefore, negative values have to be interpreted as positive effects for he HHs, that is a reduction in soil loss. Table 9 presents the full results that include the coefficients for all the covariates in the ESR model sample and the coefficients for the selection equation in which the predicted probability of adopting the practices is estimated.

Table 9: Treatment effects of anti-erosion practices on soil loss

	Anti-erosion (SE)
ATE (reduction in kg/ha of soil loss for adopters w.r.t counterfactual)	-5.479 (0.194)
ATT (reduction in kg/ha of soil loss for non adopters if they were adopters)	-6.546 (0.173)

Adopting anti-erosion measures allows HHs to obtain a reduction in soil loss of about e c 5.4 kg/ha. However, the counterfactual effect for non-adopters indicates a larger soil loss reduction of about e c6.4 kg/ha, relative to adopter HHs.

Table 9 presents the impact of a set of agricultural practices on the nutrient loss relying on the SUR empirical methodology. Only the coefficients of interest are reported while the additional covariates of the estimation are available in Appendix B5. Five sets of practices are included. First, all the agricultural inputs per hectare applied by the farmer on each plot, with their square to account for potential concavity as the quantity of inorganic fertilizers utilized increases. Second, crop diversification measures. Third, the adoption of legumes as supporting crop to maize on the same plot. Fourth, the application of fallow to the plot. The estimates point to two main results.

Table 10: Effect of practices on soil nutrients (SUR model)

	(1) l_p_grams	(2) l_n_grams	(3) l_oc_grams	(4) l_k_grams
fert1	-0.092***	-0.033*	-0.030	-0.122***
	(0.024)	(0.019)	(0.018)	(0.033)
fert2	-0.146***	-0.038*	-0.071***	-0.133***
	(0.025)	(0.020)	(0.019)	(0.034)
fert3	0.310***	-0.178***	0.168***	0.515***
	(0.065)	(0.050)	(0.049)	(0.087)
fert4	-0.079	-0.012	0.046	-0.078
	(0.080)	(0.062)	(0.060)	(0.107)
fert1^2	0.023***	-0.004	0.005*	0.034***
	(0.004)	(0.003)	(0.003)	(0.006)
fert2^2	0.029***	0.010***	0.014	0.039***
	(0.005)	(0.004)	(0.013)	(0.006)
fert3^2	-0.041***	0.041***	-0.035***	-0.074***
	(0.014)	(0.011)	(0.010)	(0.018)

fert4^2	0.018	0.002	-0.008	0.018
	(0.015)	(0.011)	(0.011)	(0.020)
D_S_HH	-0.404***	-0.236***	0.215***	0.493***
	(0.027)	(0.021)	(0.020)	(0.036)
D_crop_legumes	-0.109***	-0.068**	0.073**	-0.201***
	(0.042)	(0.032)	(0.031)	(0.055)
D_fallow	0.143***	0.154***	-0.024	0.004
	(0.033)	(0.026)	(0.025)	(0.045)
N	9255			

Standard errors, clustered at HH level, are in parentheses. Statistical significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Estimates include a control for a year dummy (2013).

Firstly, crop diversification reduces the loss of P and N. Additionally, according to Snapp *et al.* (2014), a factor that consistently influences maize yield response to nitrogen is the rotation with other crops such as with a legume crop. Legume residues are N-enriched, containing 3 to 5% N compared to 1 to 2% N in cereal residues. This is due to the biological N-fixation capacity of most legumes through a symbiotic relationship with rhizobia soil bacteria. Legumes characterized by longer growing periods and producing vegetative matter over 6 to 10 months are able to fix larger amounts of N than food legumes such as the common bean and soybean with a shorter 3 to 4 month growing period. Second, the fallow has minimal impact on reducing the loss of nutrients. Building on this preliminary analysis, the selected agricultural practices are included in the maize production function in order to estimate their potential impact in mitigating the reduction of maize productivity due to the soil and nutrient loss.

8.2 The impact of the anti-erosion measure on soil loss

Figure 13 presents the maize yield when different anti-erosion measures are implemented by the rural HHs. The analysis is based on elasticities obtained by including the interaction terms between the anti-erosion measure and soil loss[2].

Figure 13 compares, by considering three soil loss scenarios (10%, 20% and 50% increase in soil loss), the expected maize productivity when each of these practices is implemented.

In each of the three soil loss scenarios, as well as in the status quo (current loss rate), the most effective practices are represented by vetiver grass and terraces. In particular, in the

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[2] The estimates are available upon request

status quo, the adoption of the two practices increases the productivity of about 275 kg/ha and 200 kg/ha as opposed to non-adoption. Tree belts and erosion control bunds produce much lower impacts in terms of productivity growth, which range from about 80 to 120 kg/ha, depending on the severity of soil loss scenario. The mitigation loss at the national level in terms of monetary value is presented for each agricultural practices considered above.

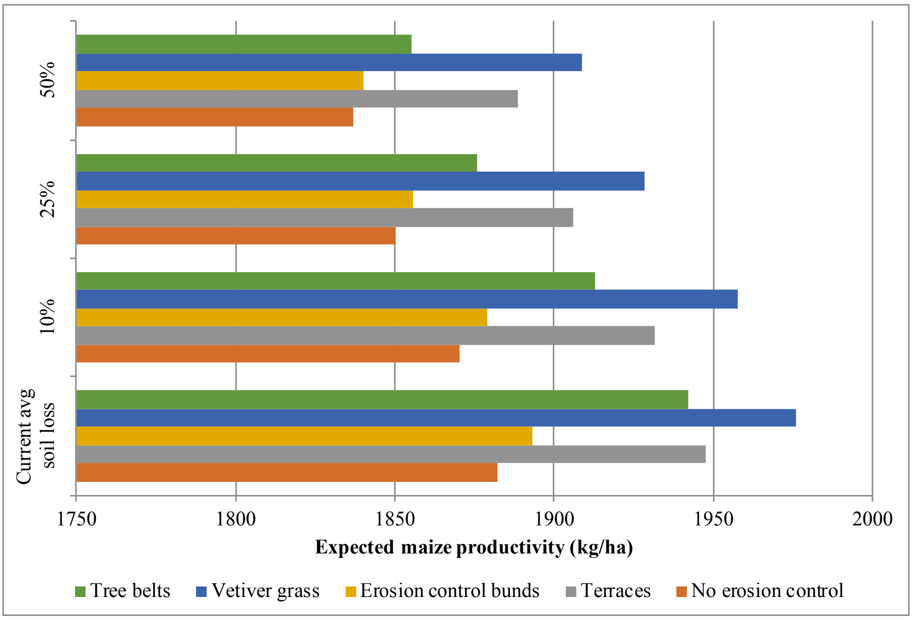
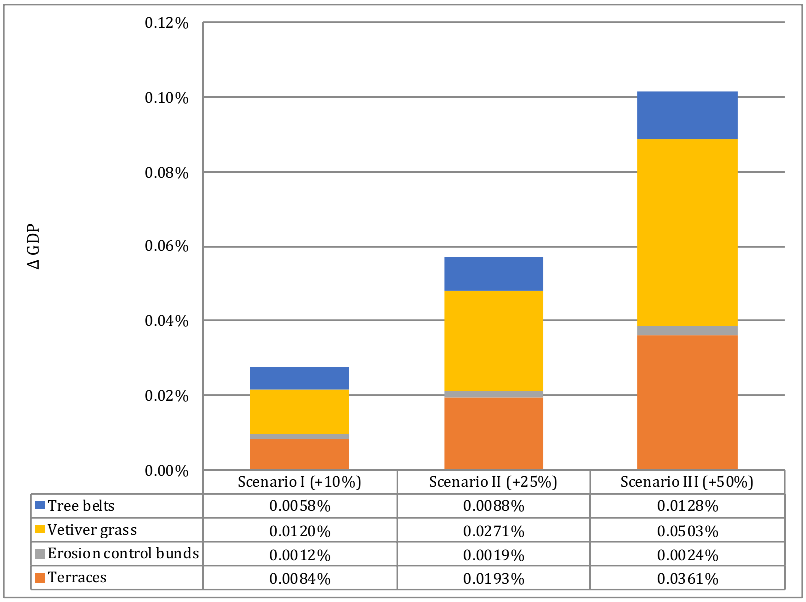


Figure 13: Expected maize productivity with anti-erosion measures, by different scenarios of soil loss

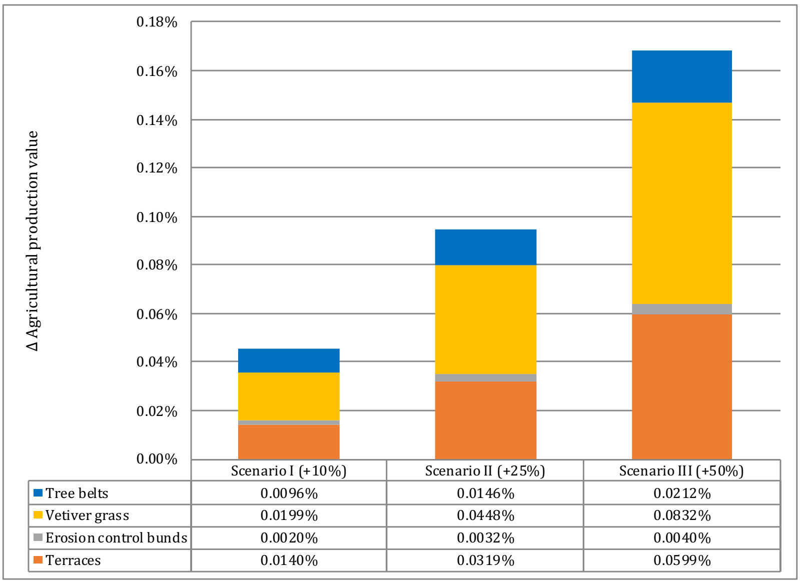
With respect to the loss of 0.260% of GDP (First Scenario), when no anti-erosion practices are adopted, the adoption of vetiver grass determines a reduction of this loss of 0.012%, shifting the national loss by -0.260% to -0.248% in terms of GDP. Similarly, in Figure 15 we present the same figures when considering the mitigation impact in terms of total agricultural production value and with respect to the baseline scenario already presented in Figure 9.

Figure 14 shows the GDP loss (illustrated in Figure 9) due to the adoption, on the average population, of each single practice separately and for each scenario.



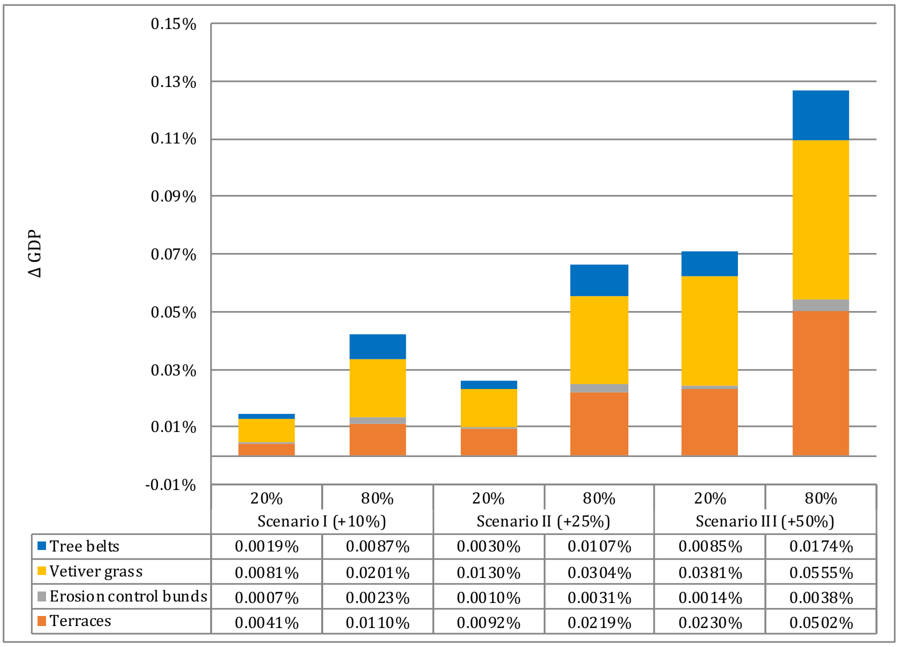
	Scenario I (+10%)	Scenario II (+25%)	Scenario III (+50%)
🟦 Tree belts	0.0058%	0.0088%	0.0128%
🟨 Vetiver grass	0.0120%	0.0271%	0.0503%
▨ Erosion control bunds	0.0012%	0.0019%	0.0024%
🟧 Terraces	0.0084%	0.0193%	0.0361%

Figure 14: reduction of GDP loss of anti-erosion measures with respect the case with no measures, for different soil loss scenarios



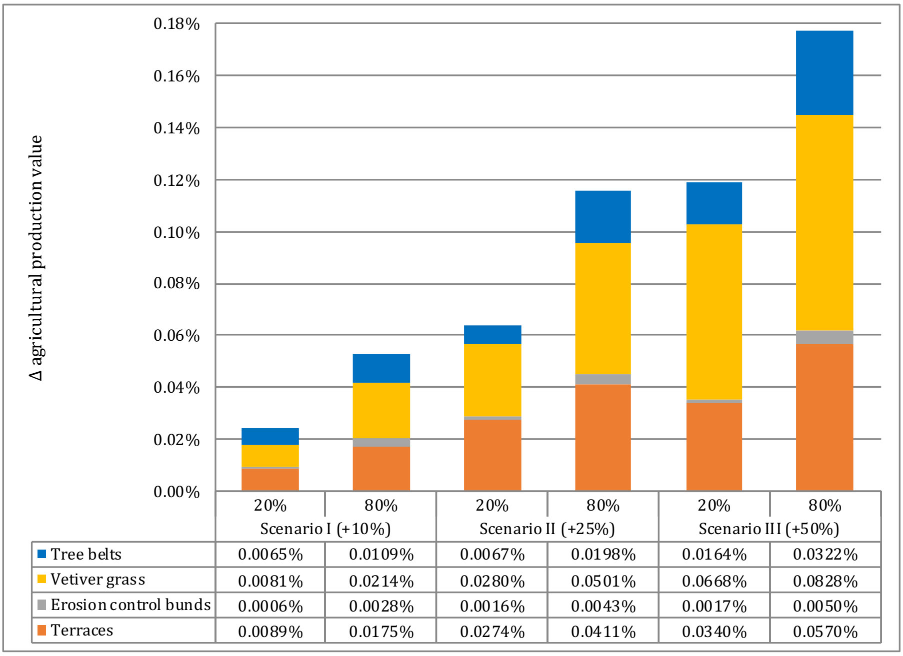
	Scenario I (+10%)	Scenario II (+25%)	Scenario III (+50%)
🟦 Tree belts	0.0096%	0.0146%	0.0212%
🟨 Vetiver grass	0.0199%	0.0448%	0.0832%
▨ Erosion control bunds	0.0020%	0.0032%	0.0040%
🟧 Terraces	0.0140%	0.0319%	0.0599%

Figure 15: reduction of agricultural production value loss of anti-erosion measures with respect the case with no measures, for different soil loss scenarios



	Scenario I (+10%)		Scenario II (+25%)		Scenario III (+50%)	
	20%	80%	20%	80%	20%	80%
🟦 Tree belts	0.0019%	0.0087%	0.0030%	0.0107%	0.0085%	0.0174%
🟨 Vetiver grass	0.0081%	0.0201%	0.0130%	0.0304%	0.0381%	0.0555%
⬜ Erosion control bunds	0.0007%	0.0023%	0.0010%	0.0031%	0.0014%	0.0038%
🟧 Terraces	0.0041%	0.0110%	0.0092%	0.0219%	0.0230%	0.0502%

Figure 16: Reduction of GDP loss of anti-erosion measures with respect to the case with no measures, for different soil loss scenarios and proportion of adopters



	Scenario I (+10%)		Scenario II (+25%)		Scenario III (+50%)	
	20%	80%	20%	80%	20%	80%
🟦 Tree belts	0.0065%	0.0109%	0.0067%	0.0198%	0.0164%	0.0322%
🟨 Vetiver grass	0.0081%	0.0214%	0.0280%	0.0501%	0.0668%	0.0828%
⬜ Erosion control bunds	0.0006%	0.0028%	0.0016%	0.0043%	0.0017%	0.0050%
🟧 Terraces	0.0089%	0.0175%	0.0274%	0.0411%	0.0340%	0.0570%

Figure 17: Reduction in agricultural production value of anti-erosion measures with respect to the case with no measures, for different soil loss scenarios and proportion of adopters

In all the soil loss scenarios, the highest economic mitigation impact results from the adoption of vetiver grass, followed by terraces, tree belts and bunds. The effectiveness of these practices should be assessed at a finer geographical level so as to make specific suggestions. However, this first assessment contributes to a national oriented strategy to indicate priorities of action.

Figure 16 and Figure 17 show the same results as the figures described above but simulating different rates of adoption of practices instead of the average adoption at the national level illustrated above. While the scenarios of soil loss remain the same, the mitigation impact changes when the practices are adopted by 20% of the rural population with lower agricultural income and when the practices are adopted by 80% of the rural population.

8.3 The impact of nutrients replacement practices

In this section the mitigation impact of crop diversification and legumes intercropping on all nutrients loss is assessed. Moreover, we estimate the optimal use of fertilizer application per hectare, in terms of mitigating the impact of N, P, and K on agricultural productivity, to provide policy makers with recommendations regarding inorganic fertilizer requirements.

Table 11 reports the impact of the legumes intercropping with maize on N and P (the impact on K is not significant). The adoption of legume intercropping seems to increase the expected maize productivity as opposed to the non-adoption case. This effect is more pronounced as the N loss increases, while it is less relevant for increasing levels of P loss.

Table 11 shows the expected productivity at the national level according to the application of different levels of crop diversification into a plot and by scenarios of nutrient loss[3]. We see that for all nutrients, the diversification seems to provide better results than mono-cropping only when such diversification is medium-high or high. Moreover, it can be observed that as the rate of nutrient loss increases, the mitigation impact of crop diversification also increases.

Table 12 alternatively reports the impact of legume intercropping with maize on N and P (the impact on K is not significant). The adoption of legumes intercropping seems to increase the expected maize productivity as opposed to the non-adoption case and this effect is more pronounced as the N loss increases, while it is less relevant for increasing levels of P loss.

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[3] Full estimates are available upon request.

Table 11: Expected maize productivity (kg/ha) for different levels of crop diversification and nutrients loss

Crop diversification	kg/ha of N loss			kg/ha of K loss			kg/ha of P loss		
	0.5	4	22	0.007	0.105	0.403	0.007	0.02	0.150
No diversification	1884.2	2004.7	1797.7	1861.0	1865.5	2092.4	1995.2	1904.4	1722.9
Low	1777.6	1935.5	1822.1	1802.1	1758.0	2053.4	1865.7	1841.4	1771.1
Medium-low	1708.0	1891.4	1841.0	1759.5	1670.3	1904.4	1767.8	1777.5	1773.1
Medium-high	1736.2	1923.9	1813.6	1814.1	1805.1	2010.6	1835.8	1784.9	1674.7
High	1758.9	1964.6	1860.8	1866.7	1904.0	2136.7	1928.4	1929.2	1782.4

Table 12: Expected maize productivity for adoption of legumes intercropping and different rates of nutrients loss

Legumes	kg/ha of N loss			kg/ha of P loss		
	0.5	4	22	0.007	0.02	0.150
No legumes	1740.5	1684.6	1561.1	1895.2	1958.2	1805.8
Yes legumes	1928.6	1939.2	1921.6	1916.7	2027.1	1889.5

Figures 18, 19, 20 and 21 report the expected maize productivity for increasing application rates of Chitowe and Urea fertilizers at increasing rates of N and P loss. It can be noted that in the case of Chitowe and Urea fertilizers, the optimal rate of application is around 180 and 270 kg/ha, respectively. Moreover, according to Figure 5, an intermediate value of N loss maximizes productivity. Similarly, the recommended rate of Chitowe and Urea fertilizers to maximize maize productivity when P loss increases, are 190 and 270 kg/ha, respectively.

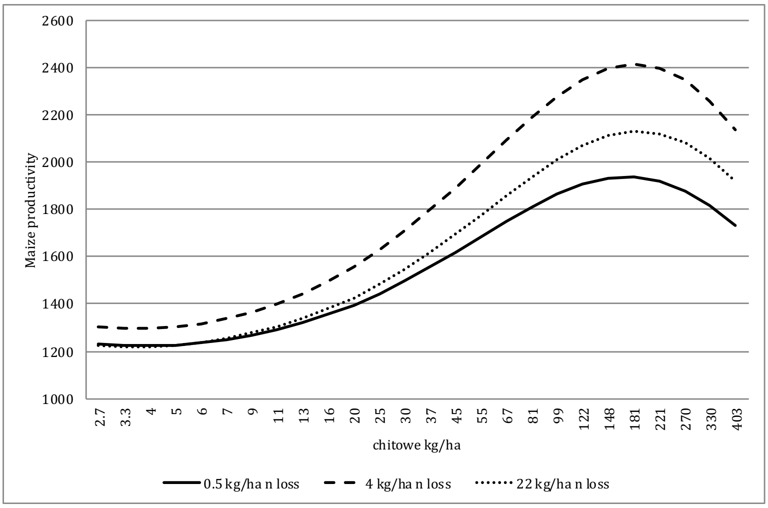


Figure 18: Impact of NPK (chitowe) kg/ha on maize productivity, for different levels of nitrogen loss

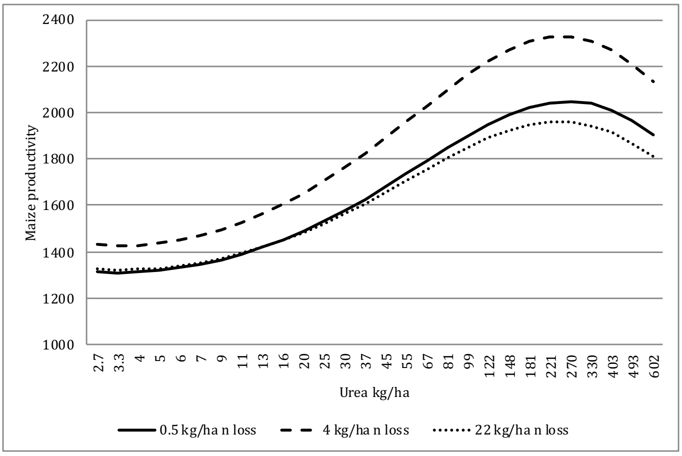


Figure 19: Impact of Urea kg/ha on maize productivity, for different levels of nitrogen loss

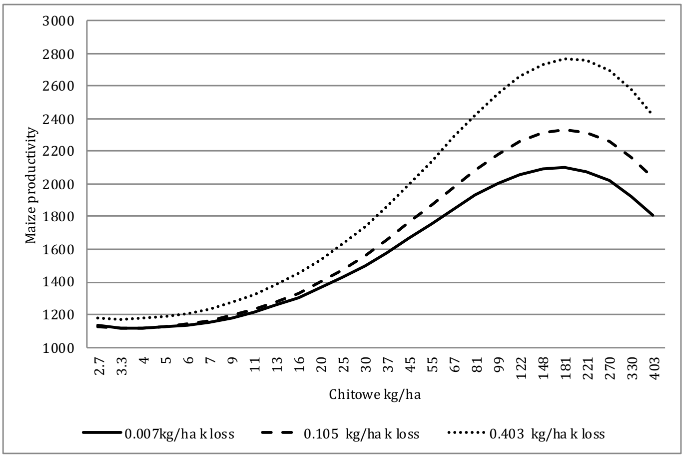


Figure 20: Impact of NPK (chitowe) kg/ha on maize productivity, for different levels of potassium loss

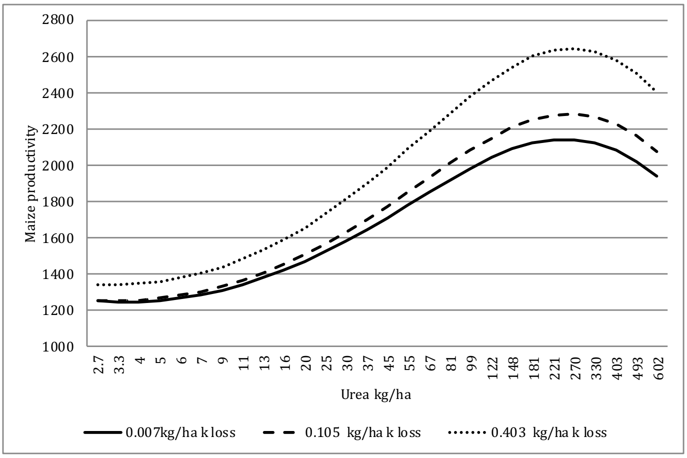


Figure 21: Impact of Urea kg/ha on maize productivity, for different levels of phosphorus loss

9 Adoption of recommended practices: impact on profitability

We have illustrated the effects of soil and nutrient loss on productivity, and potential measures that can help mitigate these effects. We have also demonstrated that productivity loss caused by land degradation can be expressed in terms of macroeconomic national indicators. On the other hand, the adoption of these practices is easy. Some of these require HHs to sustain variable costs (fertilizer application), while others come at a fixed cost (anti-erosion practices) or at non-financial costs (crop diversification and legumes intercropping). In this section we focus on practices aimed at reducing N loss, which has the greatest impact on productivity.

Chemical fertilizers have a high market price, and are difficult for smallholders and poor farmers to access in a sustainable manner. Their application is supported by the FISP, which subsidizes the use of UREA and NPK (chitowe) by distributing vouchers to be redeemed at a reduced price.

Figure 22 shows the total HH crop revenue function and total agricultural costs for the current level of N loss (4 kg/ha) and a projected level of loss of 22 kg/ha. These curves are drawn as a function of the Chitowe application rate per hectare. The revenues are obtained by relying on the expected productivity illustrated in Figure 18 and multiplying by the farm gate price of one kg of maize. The costs are a function of fertilizer quantity and the FISP average price or the market price.

The distance between the revenue and cost function represents average HH profits as fertilizer application increases. The higher the distance, the higher the profits. As expected, the application rate that maximizes profit is different from the one that maximizes the productivity, and corresponds to 168 kg/ha under the FISP price regime and 111 kg/ha at the full market price, when the N loss is at the current level. When losses increase, the profit maximizing quantities are respectively 149 kg/ha and 101 kg/ha.

Moreover, the profit maximizing Urea quantities at the FISP and full market prices are respectively equal to 173 kg/ha and 116 kg/ha with the current N loss being 125 kg/ha and 79 kg/ha for increasing N loss.

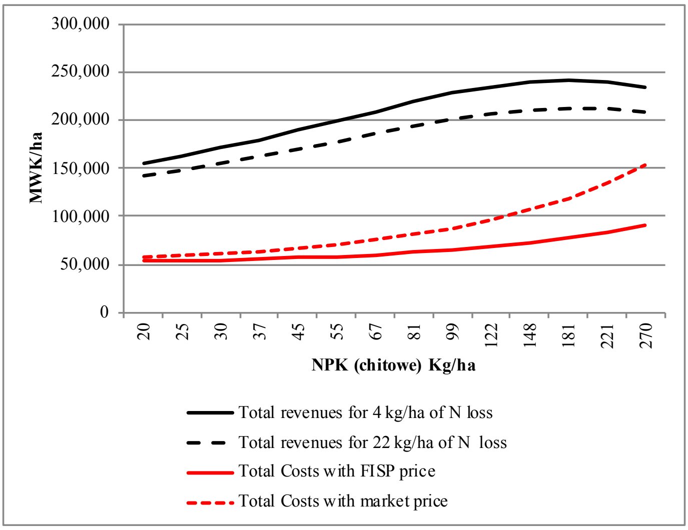


Figure 22: Total revenues and cost for N loss increase, by increasing levels of NPK (Chitowe) application rates

Figure 23 and Figure 24, make explicit the average maize profits that farmers obtain at the current situation of N loss and NPK and Urea application rates, and the profits that they would obtain at the recommended rates.

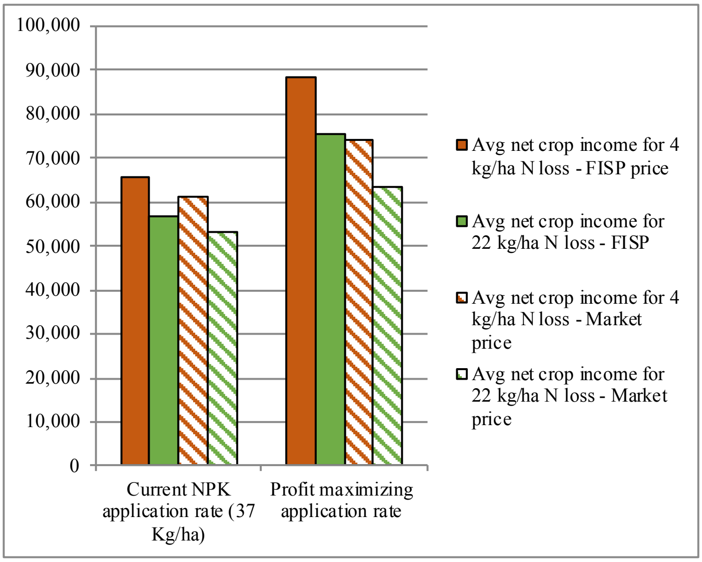


Figure 23: Total average net crop income (profits) for N loss increase, comparison between the current and the profit NPK maximizing application rate.

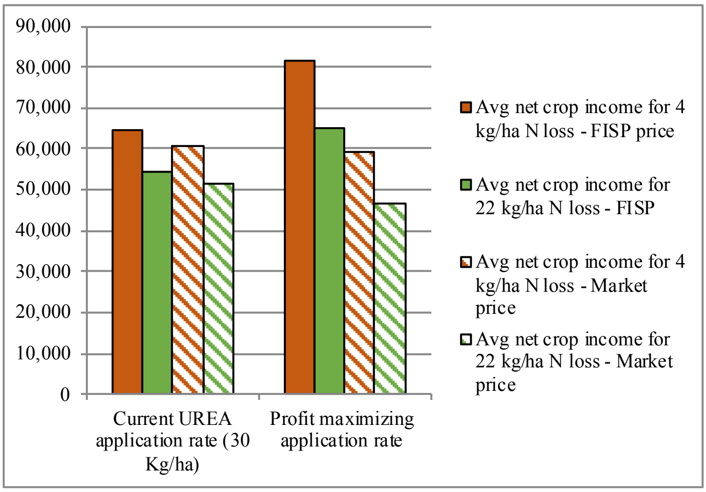


Figure 24: Total average net crop income (profits) for N loss increase, comparison between the current and the profit Urea maximizing application rate.

Figure 23 and Figure 24 show the average net crop income (profits) for N loss increase by comparing the current and profit maximizing application rates for both NPK and Urea. From these figures it is clear that at the current NPK and Urea application rates, an increase in soil loss would reduce the profitability by around 10.7% (from 65000 MWK to 58000 MWK), while using the recommended rates would increase the profits by 13.1% even with increasing N loss.

To further explore the profitability of different fertilizers application rates, we report the "private" Benefit-Cost (B/C) ratio of the current and recommended Chitowe rates (Figure 25). We can see that the highest B/C ratio is obtained for recommended rates of fertilizers application, when the price of these is subsidized. On the contrary, an increase N loss, with the current fertilizer application, push HH that are not under FISP to obtain average net benefits equal to 1.

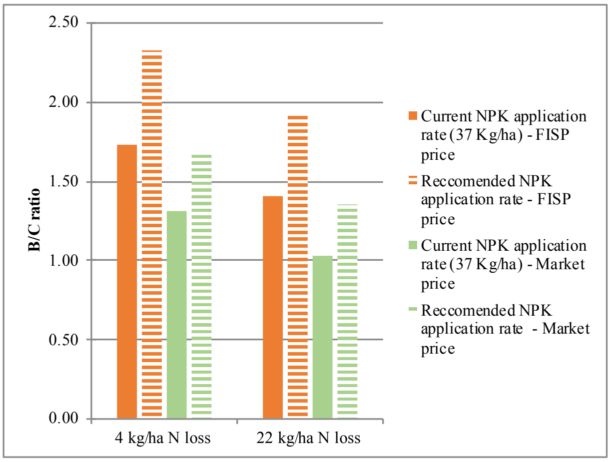


Figure 25: Benefit-Cost ratio for increasing N loss, comparison between the current and the recommended NPK (chitowe) application rates.

It is important to stress that all these figures intend for all the other variables to remain the same. This implies that the B/C ratio in Figure 25 is a consequence of increasing only the Chitowe application maintaining all the other inputs at the current level. Nevertheless, since the Urea estimation also shows the same figures, and considering the decreasing marginal productivity of both fertilizers, the impact of increasing rates of both NPK and Urea at the same time, would produce a resulting impact equal to an average of the profits given in Figure 23 and Figure 24, rather than a summation of the two.

The previous analysis can be broken down to account for different groups of the population. The findings in Section 6 and Appendix B5 can be used to show that changing the agro-ecological zones or varying the characteristics of the farmer could produce different marginal effects of nutrient loss on maize productivity, implying that the net crop income could also vary across different segments of the population.

Table 12 illustrates the current and the profit maximizing NPK application rates with related profits, distinguishing by agroecological zones, FISP participation and wealth status. The first 4 columns report the current NPK application rate and the relative profits for FISP participation. The other columns report the same information but simulate the profits obtained by each category of farmers according to the profit maximizing rate. In addition, a column gives the profits for each kilogram of fertilizer applied when farmers maximize the profits. Some useful results can be highlighted:

1. Farmers that are not under the FISP always have lower current application rates of fertilizer underlining the low affordability of commercial fertilizers (column 1 vs 3);
2. Poorer farmers that do not participate to the FISP have almost zero chemical fertilizer application rates (raw Poor, column 3);
3. Assuming that the current FISP recipients remain in the program, the profit maximizing rate of fertilizer application when the N loss shifts from 4 to 22 kg/ha should increase on average by 100 Kg/ha with respect to the current application (column 5 vs 1), even though the related increase in profits does not follow the same dynamics (see columns 2 and 7);
4. The farmers that gain the most from switching to the profit maximizing rate are the poor ones (compare column 2 with 6 and 4 with 9). Nevertheless, columns 7 and 10 show that the profits for kilograms of chemical fertilizer applied are the lowest for poor HHs (especially for those living in tropic/warm and semi-arid agroecological zones) while they are the highest for all wealth classes in tropic cool sub-humid zone;
5. Among the middle and wealthier classes, those currently targeted by the FISP are less responsive to fertilizer use than non-participants (in all the agroecological zones, values in column 10 are higher than the ones in column 7) indicating that the FISP inclusion rules could be reviewed by selecting, not taking wealth into consideration, farmers that are more efficient than the current ones.

Table 13: current and recommended NPK application rates and related profits for N loss increase, by agroecological zones, FISP participation and wealth status.

	4 Kg/ha N loss				22 Kg/ha N loss					
	FISP participant (58%)		Non-participant (42%)		FISP participant			Non-participant		
Wealth class	Current Chitowe application Kg/ha	Net crop income (MWK)	Kg/ha	Net crop income (MWK)	Profit Maximizing Chitowe applications Kg/ha	Net crop income (MWK)	profit/ kg	Kg/ha	Net crop income (MWK)	profit/kg
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Tropic cool - subhumid									
Poor	76.42	51,185	6.42	29,187	178	67,157	377	126	44,398	352
Middle	58.08	69,324	28.33	55,188	172	77,458	450	120	70,854	590
Well endowed	62.54	71,123	54.76	68,323	155	79,343	512	112	71,800	641
	Tropic cool - semiarid									
Poor	72.24	49,168	3.37	27,296	174	65,012	374	123	42,214	343
Middle	53.90	67,307	21.45	53,297	168	75,313	448	117	68,670	587
Well endowed	58.36	69,106	53.71	66,432	151	77,198	511	109	69,616	639
	Tropic warm - subhumid									
Poor	70.07	48,291	8.11	28,304	171	63,457	371	119	40,891	344
Middle	51.73	66,430	25.73	54,305	165	73,758	447	113	67,347	596
Well endowed	56.19	68,229	50.76	67,451	148	75,643	511	105	68,293	650
	Tropic warm - semiarid									
Poor	67.92	49,227	4.45	27,209	166	60,936	367	115	38,350	333
Middle	49.58	67,366	26.36	53,210	160	73,237	458	109	64,806	595
Well endowed	54.04	69,165	52.79	66,345	143	74,122	518	101	65,752	651

Following result 3, we estimate the "social" (farmers + government) B/C ratio by bringing all current recipients to the recommended rates when soil loss increases and the price of fertilizers is subsidized. Table 14 shows that the B/C is lower than one. The reasons are twofold. First, the high provisioning cost sustained by the government and, the fact that many FISP recipients are less productive than non-recipients (result 6).

Table 14: Social (farmers + government) benefit/cost ratio to shift the current FISP recipient HHs from the current fertilizer application rate to the profit maximizing rate

A) Delta fertilizer requirements (to switch from current to recommended)	210%
B) Average delta net crop income of FISP participant (MWK)	14,000
C) Current (2016) FISP recipients (HH)	900,000
D) Current Government FISP cost (only fertilizers) (MWK)	27,000,000,000
E) Delta benefits of FISP participant (to switch from current to recommended rate) (B*C)	12,600,000,000
F) Delta government FISP cost ((A*D)-D)	29,700,000,000
B/C ratio of subsidizing the recommended fertilizer rate when the N loss increases (E/F)	0.42

Data source: Authors estimation on data from Malawi Government Annual Economic Report 2017 and 2018/19 Financial Statement.

The analysis shows that the current FISP scheme may be further improved as the increase in farmers' profits induced by subsidies does not fully compensate for government expenditures. Nevertheless, it is worth noting that the farmers that benefit from the FISP – especially the poor – improve their net income, especially in the case of more severe nutrient loss.

Increasing access to commercial fertilizers, by excluding HHs that are more capable of buying from the private sector, would reduce the Government's expenditures. To this end, Table 15 highlights the socio-economic characteristics of HHs that increases the probability of purchasing commercial fertilizers, comparing these with the variable that increases the probability of being FISP recipients. A positive sign means that the variable increases the probability, while the opposite is true for a negative sign.

Table 15: determinants of FISP participation and commercial fertilizers purchases

Determinant	Effect on:	
	commercial fertilizer purchase	FISP coupon eligibility
Age (HH head)	n.s.	+
Female HH head	n.s.	n.s.
Education (HH head)	+	–
HH size	+	+
Distance to main urban centre	n.s.	-
Plot area	n.s.	n.s.
Drought shock (SPEI>1.5)	n.s.	–
Parliament member	n.s.	+
Wealth class	+	n.s.
Plot owner	+	+

n.s. indicates not significant variable. + and – indicates, respectively, positive and negative correlation

The probability of receiving a coupon is higher for older HH heads and lower in more educated HH heads. At the HH level, larger families, and those residing farther from the main urban centre, are more likely to get the FISP coupon. Surprisingly, HHs that are more subject to drought shocks (SPEI >=1.5 s.d.) are associated with less coupons. Moreover, HHs that own their plots and have a parliament member in their family are more likely to receive a coupon.

HH likelihood of purchasing commercial fertilizers is negatively affected by the education level, the distance from the main urban centre and a climatic shock experience. On the other hand, HH who are likely to purchase commercial fertilizers are well educated, larger in size, wealthier and tend to be the owners of their plots.

If it is true that educated, land-owning, larger and wealthier farmers are more likely to have access to commercial fertilizers , the Government should also provide the marginalized HHs with vouchers, as these HHs are the most affected by erosion and nutrient loss. Table 13, reports the distribution of current FISP recipients, by AEZ and wealth class. While we can see that the majority of recipients (41% and 36%) are in warmer agroecological zones, we can also see that the poor HHs are those more likely to be targeted.

Since we know from Table 13, that non-recipients of FISP are more efficient in terms of fertilizer use in the middle wealth class, the Government could shift a share of vouchers from the current recipients that are more likely to purchase commercial (owner, highly educated and large HH members number) fertilizers to those non-recipients that are less likely to purchase commercial fertilizers. With this adjustment the social B/C ratio would switch from the 0.42 estimated above, to 0.89, which is closer to the desired value of 1.

Table 16: FISP Recipient proportion on total HH, by agroecological zone and wealth class

	FISP recipients proportion (%)			
	Tropic cool - subhumid 0.13	Tropic cool - semiarid 0.09	Tropic warm - subhumid 0.36	Tropic warm - semiarid 0.41
Poor	0.41	0.66	0.51	0.62
Middle	0.48	0.28	0.42	0.33
Well endowed	0.09	0.04	0.06	0.04

Alternatively, transferring vouchers from well-endowed HHs in warm agroecological zone, the less profitable conditions in terms of fertilizer use, to poor HHs in cool subhumid agroecological zones, the most profitable, would increase the equity of FISP but the B/C ratio improvement would be limited (from 0.42 to 0.54).

An alternative solution could be encouraging other agricultural practices able to substitute the mitigation effect provided by fertilizer use to the issue of nutrients loss. Among the practices evaluated in Section 8.1, the most effective seems to be legume intercropping. Table 17 replicates the results reported in Table 13 also calculating the net crop income and the profit maximizing fertilizer rate required in the case of nutrient loss increases when the farmers legume intercropping. In the first 6 columns, we report descriptive statistics on the percentage of the population applying this practice between FISP particpants and non-participants, and according to the wealth status and the agroecological zone.

It emerges that this practice is recurrent in the cool AEZ but not exploited in the warmer zones. Moreover, poor HHs adopt these practices more than others because they are likely to be more diversified, and need to reduce their personal risk of crop failure. Among the FISP participants, there is a high probability of legume intercropping adoption in the subhumid zone, while the opposite is true in the humid zones. In any case, on average, the net crop income of those HHs adopting the intercropping is higher than those not adopting the practice.

Moreover, in Section 10.3 we explained as female headed HHs are among those more likely to adopt sustainable agricultural practices such as legume intercropping, and for which the productivity gap does not exist. This group could be targeted as eligible for subsidies on legumes intercropping in order to reduce such a gender gap in terms of productivity.

Due to the capacity of legumes to fix the N (as illustrated in Table 12) it is possible to calculate the average reccomended fertilizer rate to maximize profits when the N loss increases.

Differing from the quantities reported in column (5) and (8) of Table 13, the integration of legume intercropping strongly reduces ferilizer requirements for both the FISP participants and non-participants. As a consequence of reduced costs for fertilizers, the net crop income increases substantially (around 39% on average for all the groups), pointing to an important result in terms of mitigation capacity and livelihood strategy for those affected by erosion.

Table 17: Variation in of income and profit maximizing fertilizer rate if coupled with legume intercropping

Wealth class	4 Kg/ha N loss						22 Kg/ha N loss			
	FISP participant			Non participant			FISP participant		Non participant	
	% legume intercropping (11)	Net crop income		% legume intercropping (14)	Net crop income		Profit maximizing fertilizers rate if legume intercropping applied (17)	Net crop income (18)	Profit maximizing fertilizers rate if legume intercropping applied (19)	Net crop income (20)
		Legume intercropping (12)	No Legume intercropping (13)		Legume intercropping (15)	No Legume intercropping (16)				
Tropic cool - subhumid										
Poor	22	51,185	37,907	17	44,060	32,033	77	85,157	61	56,519
Middle	19	69,324	56,046	16	62,199	50,172	71	95,458	55	82,975
Well endowed	18	71,123	57,845	13	63,998	51,971	54	97,343	47	83,921
Tropic cool - semiharid										
Poor	11	49,168	38,211	16	42,043	34,337	73	82,012	58	53,268
Middle	14	67,307	56,350	26	60,182	52,476	67	92,313	52	79,724
Well endowed	4	69,106	58,149	17	61,981	54,275	50	94,198	44	80,670
Tropic warm - subhumid										
Poor	9	48,291	33,416	5	42,166	29,542	70	79,457	54	50,992
Middle	6	66,430	51,555	5	60,305	47,681	64	89,758	48	77,448
Well endowed	6	68,229	53,354	6	62,104	49,480	47	91,643	40	78,394
Tropic warm - semi-arid										
Poor	2	51,185	36,998	5	47,260	33,124	65	75,936	50	48,139
Middle	4	69,324	55,137	2	66,199	51,263	59	86,237	44	74,595
Well endowed	3	71,123	56,936	7	67,998	53,062	42	88,122	36	75,541

It is also important to highlight that the recomended fertilizer rate for FISP participants is now similar to the the current rate of N loss (compare column 17 in Table 17, with column 1 in Table 13). In particular, well-endowed farmers should be less subsidized. On the contrary, it is optimal to increase the distribution to the middle class (Table 14). Bundling modern practices together with more responsive sustainable practices would require an additional moderate cost to the Government (due to legume seeds subsidies), however, this cost would produce a very large return. In Table 18 the B/C ratio is reported, which has a substantially different magnitude compared to the B/C ratio of subsidizing fertilizer to the profit maximizing rate presented in Table 14.

Table 18: Social (farmers + government) benefit/cost ratio to shift the current FISP recipient HHs from the current fertilizer application rate to the profit maximizing rate when legume intercropping is subsidized

A) Delta fertilizer requirement (to switch from current to recommended)	0%
B) Average delta net crop income of FISP participant without legume intercropping (MWK)	22,000
C) Potential recipients of legume seeds (HHs)	830,000
D) Additional cost to the Government for legume seeds	4,200,000,000
E) Delta total benefits of FISP participant (to switch from current to recommended rate and doing legume intercropping) (B/C)	18,260,000,000
B/C ratio of subsidizing the recommended fertilizer rate and legume intercropping when the N loss increases (E/D)	4.15

Data source: Authors estimation and Malawi Government Annual Economic Report 2017

10 National economic implications with a general equilibrium approach: trade, prices, and sectoral adjustments

In the previous sections we focused on the direct costs of soil loss represented by the loss in production. In what follows, we use a general equilibrium model to identify how market agents (i.e. firms, farmers, consumers and the government) react and adjust to the initial shock of soil loss productivity. Especially when combined with micro-econometric calibration, which we do in this report, the use of CGE models to analyse how sectoral impacts propagate to the economy as a whole represents a fruitful and standard approach in both the academic and policy environments to assess the macroeconomic impact (Böhringer & Löschel, 2006). These models simulate the functioning of an economic market system with neoclassical assumptions, such as the existence of perfect competition, full employment, the achievement of equilibrium in all markets and the presence of international trade. Flexibility, or the variation of relative prices, is the means by which, in markets characterized by conditions of perfect competition, it is guaranteed that demand equals supply and that, whenever there is an exogenous shock, a new internal balance is always ultimately reached. Within each country, perfect mobility of capital and labour between the economic sectors is assumed. Land is a sluggish endowment and a certain degree of mobility between different sectors is assumed while natural resources are immobile. In these models, representative agents (firms, consumers and government) respond to changes in market prices and formulate decisions to maximize their private benefits. For these features, CGE models have been applied to various sectors such as agriculture (Tsigas *et al.* 1997), tourism (Berrittella *et al.* 2006), and climate change (Bosello *et al.* 2012). More recently, CGE models have also been applied to calculate the macro-economic impacts of soil loss (Panagos *et al.*, 2018) in the EU and in Sub-Saharan Africa (Yaron *et al.* 2010).

10.1 Scenarios and results

For the purpose of this study, we use the database and the static model developed by the Global Trade Policy Analysis Project (GTAP). The GTAP is an international consortium that includes, among others, institutions such as the World Bank, the OECD, the WTO, the UNCTAD (United Nations Conference on Trade and Development), the Commission of the European Union and the United States International Trade Commission.

In particular, the version of the model employed is the standard GTAP (Hertel, 1997): the database is the latest released, version 9.2 (Aguiar *et al.*, 2016) whose base year is 2011. This means that all monetary values of the data are in 2011 current US$. The simulations are performed with the reference year being 2011 and represents comparative static exercises where specific shocks are introduced directly into the base year and evaluated without other perturbations (i.e. ceteris paribus). In this case, the global CGE model is used to compute the impacts on the agriculture sector, trade patterns and GDP of Malawi using the crop productivity loss related to soil erosion as an exogenous input to the model. This negative shock on crop yield affects production and prices of agricultural commodities, thereby shifting their supply and demand. As a result, the shock impacts all other markets linked directly or indirectly to agriculture. This process will finally determine a new equilibrium, for which the projected GDP and new import and export flows are calculated.

We carried out a comparative static analysis where only the negative shock on land productivity is given. The simulations employ the elasticity obtained by means of econometric estimates presented in Section 5.1. The scenarios assume three different increases in soil loss with respect to the model base year: 10%, 25% and 50% (see Table 19). The agricultural productivity loss is expected to affect all the agricultural sectors (sectors 01-09 in Table 20) of the Malawian economy while no other shocks affect the rest of the regions of the World.

Table 19: Scenario description

1 – Soil loss increase of 10% wrt to 2011: "SL10" (i.e. 2.250% agricultural productivity loss)
2 - Soil loss increase of 25% wrt to 2011: "SL25" (i.e. 5.625% agricultural productivity loss)
3 - Soil loss increase of 50% wrt to 2011: "SL50" (i.e. 11.250% agricultural productivity loss)

Table 20 presents the regional and sectoral details considered in the simulation. Given the focus of the study, the emphasis is put on the agricultural sectors with nine agricultural products. Similarly, country aggregation has been decided in order to single out the most important trading partners of Malawi.

Table 20: Sectoral and regional details of the model

Regions	Sectors
01 Malawi	01 Rice
02 SSA(Sub-saharan Africa)	02 Wheat
03 Oceania (Australia, New Zealand)	03 Maize
04 China	04 Cereal grains nec
05 Asia	05 Vegetables, fruits, nuts
06 SEAsia	06 Oil Seeds
07 SouthAsia	07 Sugar cane, sugar beet
08 USA	08 Plant-based fibers
09 Rest of North America	09 Crops nec
10 Latin America	10 Timber
11 European Union 28	11 Livestock and Meat Products
12 Russia	12 Coal
13 Middle East and North Africa	13 Oil
14 Rest of the World	14 Gas
	15 Petroleum Products
	16 Electricity
	17 Processed Food
	18 Textiles and Clothing
	19 Chemicals
	20 Light Manufacturing
	21 Heavy Manufacturing
	22 Transport and Communication
	23 Other Services

Figure 26 reports the % macro-sectoral composition of Malawi value added as reported by the World bank (WDI, 2016) in 2011 and as is in the model database. The matching between the two is almost perfect, featuring the agricultural, industrial and services macro-sectors contributing the 31.2%, 16.7% and 57.0% to total value added, respectively.

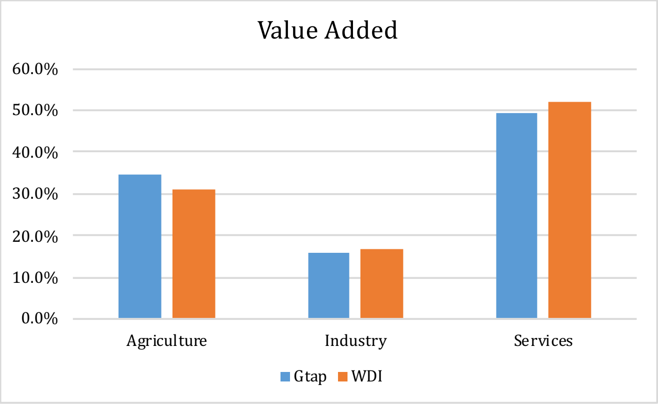


Figure 26: (%) shares of sectoral Value Added in Malawi, Gtap database and World Bank WDI in 2011

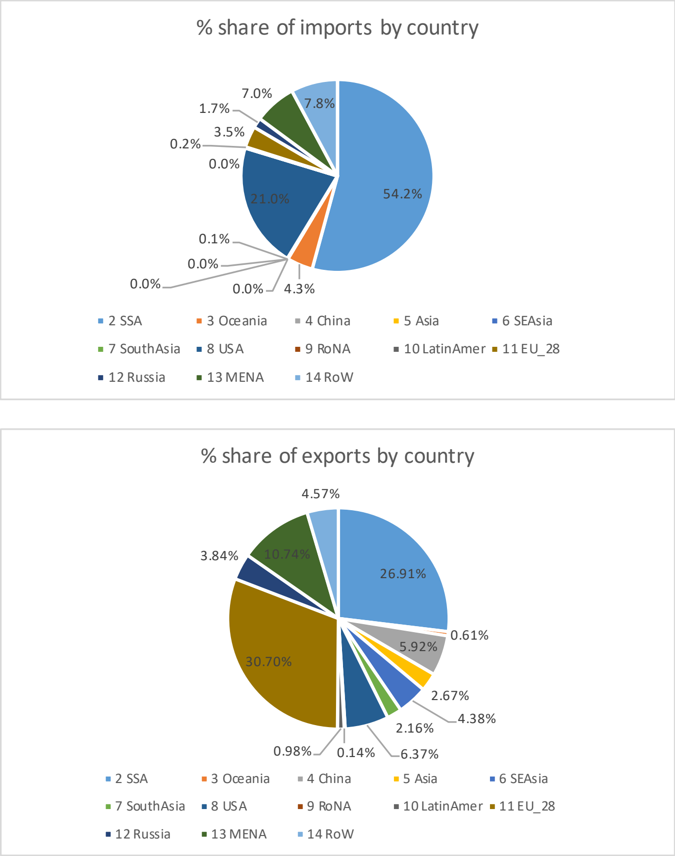


Figure 27: Agriculture share (%) of exports and imports by trading partner in 2011

Figures 27 and Figure 28 above report the share of exports and imports of Malawi in 2011 per trading partner and per crop respectively as resulting from the GTAP database. They replicate reasonably well the patterns of Malawian international trade, featuring Europe, the rest of Sub-Saharan Africa and the Middle East as the major destination markets. Imports are sourced primarily from rest of Sub-Saharan Africa and Russia.

It is worth noting that "other crops" represent almost 80% of all cereal exports and 42% of exports overall. Wheat constitutes the other most important crop in terms of imports. Maize accounts for 8.4% of exports while its share of imports is very small.

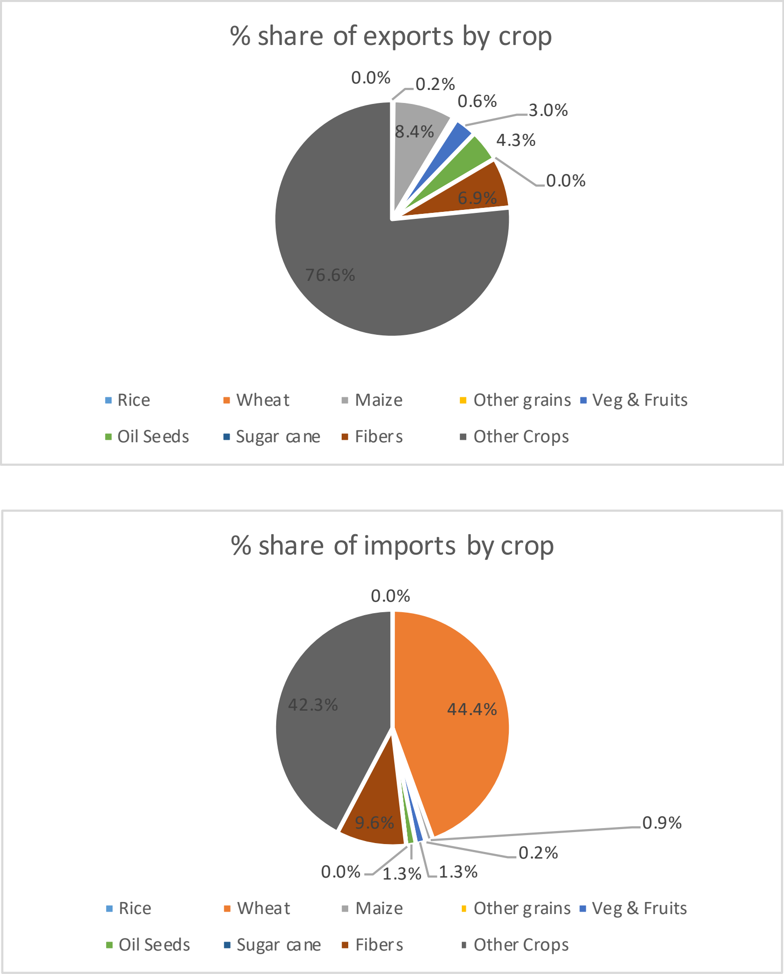
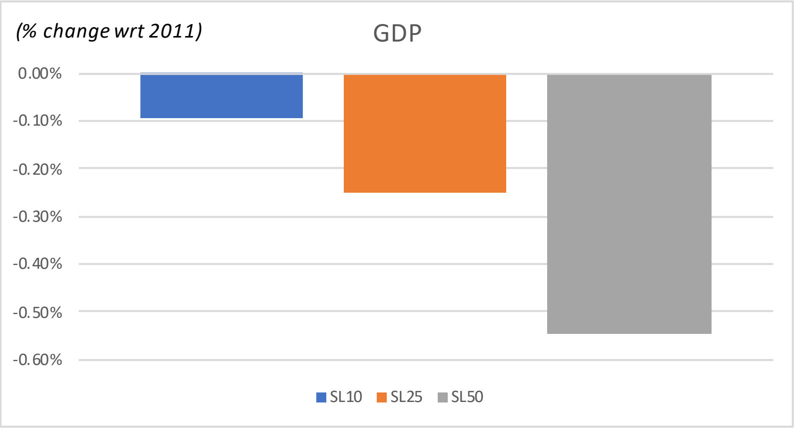


Figure 28: Agriculture share (%) of exports and imports by crop in 2011

Turning to the results of the CGE model simulation, welfare and GDP fall, due to the decline in land productivity, while crop prices increase. In terms of GDP, losses induced by contraction in the agricultural sector are estimated to range between 0.10%-0.55% relative to 2011 (see

Figure 29) equivalent to 4-21 billion MWK 2016. Among the different GDP components, consumption shows the higher level of contraction (equivalent to around 16 billion MWK 2016 in the SL50 scenario). Notice that the values of GDP losses are lower than the values of agricultural production losses. The model functioning relies on market mechanisms, and when the agricultural sector contracts, factors of production are free to relocate to other sectors, thereby mitigating the overall GDP loss. Capital and labour in particular are perfectly mobile across all sectors of the economy and can adjust to a shock in a market while guarantying the full employment. This behaviour can be seen as an optimized situation where there is a fully competitive economy. Thus, the estimated economic losses should be interpreted as lower than the true levels.

Accounting for these limitations, it is important to stress that the substitution between primary factors (labour, capital and land) for the agricultural sector is not perfect. The default elasticity of substitution from the GTAP database is equal to 0.259, rather close to a complementarity condition between the factors. This assumption makes the substitution between land and labour or capital more expensive compared to a situation where this condition is not satisfied.



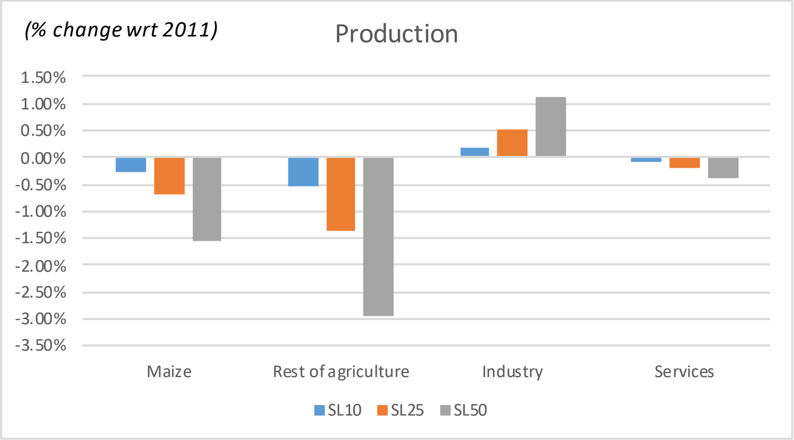


Figure 29: The economic loss due to soil loss: the impact on GDP and Production (% changes for 2011)

The total agricultural production loss due to soil erosion ranges between -0.47% and -2.67%. The decrease is larger in the "rest of agriculture" aggregate (where all sectors 01-09, excluding maize, are considered), particularly for "08 plant fibres" (i.e. cotton, flax, hemp, sisal and other raw vegetable materials used in textiles) and "09 other crops" (a GTAP aggregate which includes the tobacco plant). The reductions are -4.1% and -5.3% respectively in the SL50 scenario.

Turning to the rest of the economy, the industry sector shows a small increase in production (between 0.2% and 1.1%), while in the services the changes are negligible. These sectors can "benefit" from the decline in agricultural production, which in turn induces a decline in labour demand, a reduction in wages and, finally, a shift of unskilled workers to industry and services.

Lower levels of agricultural productivity result in an increase in production costs and consequently in an increase in market prices. The decline in land productivity increases the demand for land, therefore, market prices for this factor increase in the range 4.3% - 24.3%. Given that the total amount of land supplied is fixed, the increase in demand for land from the agricultural sectors implies a reduction of the demand for land in the meat (between -1.5% and -7.7%) and timber (between -0.5% and -2.5%) sectors.

Changes in market prices for the rest of the factors are negative. Returns to unskilled labor decrease more than returns to skilled labor (-0.6%-3.3% and -0.4%-2.5%, respectively). Thus, the decline in agricultural productivity substantially harms both agricultural and non-agricultural HHs.

Figure 30: Changes in crop prices

Exports in the agricultural sector decrease significantly both in the maize and the rest of the agricultural sectors while increase in the industry and services sectors (see Figure 31). The mechanics behind this "shift" mimic what was already represented in the sectoral production. However, few additional comments are needed. First, Malawi is a small economy in the world market and the rise in agricultural prices only marginally affects world prices. Secondly, a rather strong assumption is made in all the simulations, that no shocks occur in any of the regions and countries of the rest of world. Finally, and most importantly, the model assumes the "Armington hypothesis" (Armington 1969), which implies that imported goods are imperfect substitutes of domestic goods. This produces a slight improvement of the country's terms of trade (Figure 31): the price of Malawi's export goods increases more than the price of its import goods. In other words, two main effects are at work: a positive one because the export prices increase, which also increases the export earnings from each unit of good exported. The negative effect is given by the fact that the rest of the world faces an increased import price and substitutes Malawi's exports with ones from other countries.

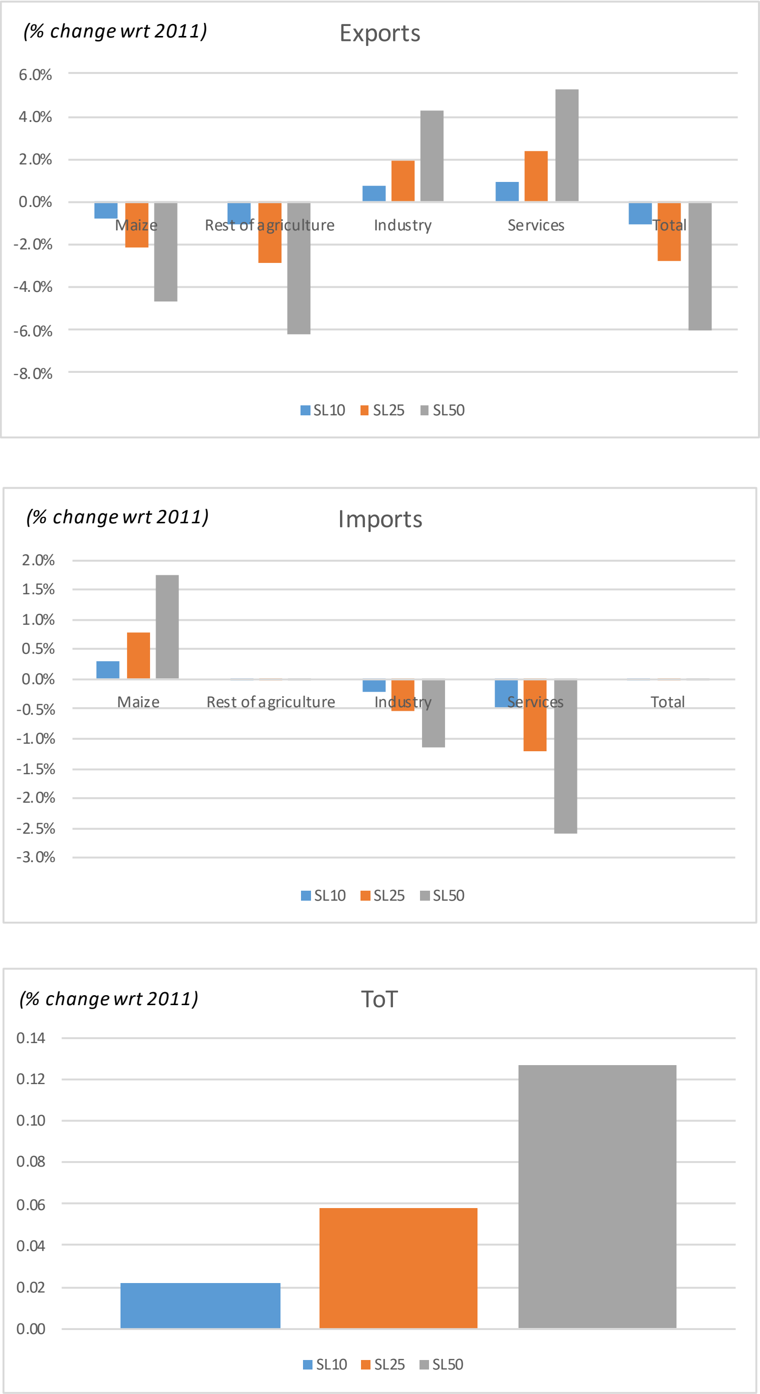


Figure 31: Changes in trade in real terms (Imports and Exports) and Terms Of Trade

11 Policy implications and conclusions

This study investigates the economic impact of soil and nutrient loss in Malawi both from a partial and general equilibrium perspective. In order to evaluate these effects, new granular data on soil and nutrient loss are employed, together with climate and socio-economic information at the HH level. Moreover, both micro-econometric and a preliminary assessment of a computable general equilibrium models are employed in order to capture both direct and indirect effects of soil and nutrient loss on the Malawian economy.

Malawi experiences a rate of losses less severe than other Sub-Saharan African countries, but the trend and the scenarios for climate change and climatic shocks are expected to exacerbate this phenomenon that is already a concern for the agricultural sector and the economy as a whole in a agriculture based country. It is, thus, of the upmost importance to provide the first economic assessment of costs associated with the degradation of soil resources.

This report focuses on the impact of soil and nutrient loss on agricultural production and welfare. Moreover, an evaluation of how these phenomena affect the more fragile groups of the population, such as the poorest HHs or women or those living in particular areas such as the semi-arid agro-ecological zones or in the South districts, is also carried out. Building on this analysis, we identify practices that can contribute to mitigate the negative microeconomic effects of broad land degradation. National level implications are then investigated in terms of GDP, poverty rate, agricultural production value, prices and net import.

Our results confirm the negative impact of soil loss on maize production and broader measures of welfare such as per capita real consumption and calorie intake, the latter being interpreted as a proxy for food security. The most fragile classes of the population are, in proportion, influenced with a higher severity. On average, these groups face negative impacts that are more than double the ones of wealthier farmers and male headed HHs.

Moreover, in the worst scenario of soil loss, Malawi would face the risk of an additional half a million individuals in extreme poverty with respect to current numbers.

Summing up the assessment of soil loss impacts, further policy intervention should aim to mitigate the productivity gap identified, and obtain an added benefit of improving key livelihood assets such as calorie intake and total consumption in HHs that are strictly dependent on agriculture. Gender gap should be a priority component of any related policy, since soil loss affects female-headed HHs considerably more than male-headed HHs. A one per cent reduction in soil loss translates into about -0.23% in maize productivity for male-headed HHs and -0.39% for the female ones. The impacts on total real per capita consumption show the same order of magnitude.

This pattern of impacts is further confirmed by hypothesizing an average loss increase to 22 tons/ha, which would yield a 32-61% loss in maize productivity. When imposing a more severe scenario with an average loss of 40 tons/ha, the expected productivity loss ranges from 39% to 77% with regard to the current baseline scenario of 10 tons/ha.

The interpretation of the effects of nutrients loss is less straightforward, since the impact depends on the balance in the soil and the interaction effects among nutrients. While N and K losses clearly have large negative effects on agricultural productivity, less evidence can be inferred for potassium and the organic content (at least under a certain threshold of loss).

In order to maximize productivity when N loss increases to 22 kg/ha, farmers should apply 150-160 kg/ha of Chitowe and Urea instead than the average of 50 currently applied. Thus, the analysis finds deviations between the current and optimal fertilizer application rate, with potential additional expenses by farmers or the government in terms of subsidies.

Policy makers should also consider that the nutrient loss anticipates – as in the case of top soil loss - differentiated impacts across different groups of the population. In the case of nitrogen (for which the most significant effects are found), the impacts on the most fragile rural farmers are more than double compared to the impact on wealthier farmers. Moreover, warm agroecological zones are those likely to be more affected by an increase in land degradation.

Some sustainable agricultural practices are shown to have a direct effect on mitigating the soil loss and consequently the economic damage caused at a national level. When considering the effects of practices, the highest economic mitigation impact results from the adoption of anti-erosion practices such as vetiver grass, followed by terraces, tree belts and bunds. When nutrient loss is accounted for, crop diversification represents a key strategy that should be supported and sustained at the political level, as it is associated with significant reduction of potassium and nitrogen loss, even considering that this practice is more frequent in female-headed HHs. In particular, a high crop diversification can increase the average productivity of around 3.5% as the N, P and K losses increase, while the legume intercropping increases the productivity by 23% when the N loss is severe.

In considering further policy interventions for mitigating the impact of nutrient loss, it is worth considering the current FISP cost, which does not seem to be strongly sustained by a relevant return in terms of social net benefits, despite the fact that farmers – especially the poorest ones – would gain net income important for their livelihood when the nutrient loss phenomena becomes more severe. Increasing the access to commercial fertilizers, excluding those HHs that are more likely to buy from the private sector, would reduce the costs to the Government. The latter should account for farmer characteristics when allocating the FISP vouchers, in order to give priority to the most marginalized farmers that suffer most from soil loss impacts. On the contrary, well-endowed farmers should be less subsidized, while an increase in distribution to the middle class would be desirable if the budget allows for it. This strategy would allow the Government to maintain current expenditures for fertilizer in order to avoid the huge increase suggested in the case of a single practice objective, resulting in a higher profitability (B/C=0.89, which is higher than B/C=0.42 of the single-policy case). The socio-economic characteristics that maximize the probability to buy from the private market are a higher age and education of the HH head, longer distance from the main urban areas, plot ownership and political activity of the HH members.

An alternative and more profitable solution may be encouraging other agricultural practices able to substitute the mitigation effect given by fertilizer use to tackle the issue of nutrientloss. The reduced costs for fertilizers is expected to increase net crop income by about 40% on average for all the groups (poor, middle and well-endowed HHs with higher benefits estimated in cool humid and subhumid agroecological zones). Integrating modern practices with the more responsive sustainable practices, including legume intercropping as an elective practice, would minimize the cost to the Government (mainly due to enlarging the distribution of subsidizing legume seeds and, ideally, providing extension services to incentivize the practice) while generating a very high return (B/C =4,15). This would represent a win-win situation, given that the impact of nutrient loss is highly variable and females are most affected. However, female HH heads are more likely to adopt legumes intercropping, hence targeting this group for subsidizing intercropping would have the twofold effect of reducing the gender productivity gap while simultaneously mitigating nutrient loss.

The national impacts of soil and nutrient loss must be intended as a lower bound considering the assumption of our models, but point out relevant implications for policy makers. Considering both partial and general equilibrium analysis, the loss in terms of GDP ranges from the 0.09-0.2% to 0.55-1.3% for low and severe scenarios of soil loss increase, respectively. However, the variation of the minimum and maximum impact is sensitive to the methodologies applied. In terms of reduction of agricultural production value, the impacts of soil loss ranges from 0.47-0.7% to 2.12-2.7%. We also report an increase in maize imports. There is also a reduction of up to more than 4% of the export value and, up to more than 6% of the agricultural sector as a whole.

In the case of a severe increase in nutrient loss, the, impact is equal to around 1.6% of the GDP and 3.4% of the agricultural production value.

If 20% of the population adopted anti-erosion practices such as vetiver grass (the most effective in mitigating soil loss), the loss in GDP would decrease by around 0.034% (saving 13 Billions of MWK), while if the proportion of the population adopting these practices was equal to 80%, the mitigation effect on GDP would be 0.055% (a saving 21 Billions of MWK).

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13 Appendix A – Methodology

The empirical approach to estimate the impact of soil and nutrient loss relies on a multi-step micro-econometric approach, utilizing data at the micro-level to aggregate information suitable for macroeconomic considerations.

This approach presents some advantages with respect to others (e.g. computable general and partial equilibrium models) since the models employed are not subject to strict assumptions such as equilibrium level conditions or representative agents. Moreover, the empirical approach is based on inferential techniques (calculation of confidence intervals, standard errors, model fitting parameters, testing) which allows for determining the causal effect of soil loss and application of agricultural practices on the outcomes with the estimation of a response function. The results are easy to interpret since responses are based on elasticity of productivity and welfare as percentage changes of outcomes given a percentage change of the main determinants (covariates). Finally, since the data sources are country-representative, the results on welfare can be generalized at the national-macro level by weighing the estimates by population weights. Such a method implies to select, as a first step, the best level of analysis to obtain the impact of the soil and nutrient loss and the application of different agricultural practices on selected indicators of agricultural production and HH welfare. Consequently, while investigating the determinants of productivity requires an analysis at the plot level to catch impacts of pure agronomic and climatic processes, the impacts on welfare are conducted at the household (HH) level to account for the socio-economic context affecting the livelihood capacity of farmers.

A1 - Quantile regression model

In order to evaluate how the soil and nutrient loss affect the agricultural production and HH welfare, or how the agricultural practices can mitigate these impacts, we estimate a quantile regression that has the advantage of capturing potential non-linear impacts thereby allowing policy implications on those mainly affected by the phenomena of soil loss. Indeed, soil loss can have impacts that are sensitive to different social and economic classes.. The best empirical solution to this issue is a model which provides quantiles of conditional distribution of the response variable expressed as functions of observed covariates, providing a detailed view of potential relationship between variables in a socio-economic process provided by approaches which results in estimates approximating only the conditional mean of the dependent variable given a certain value for the vector of covariates (Koenker, 2005). Several recent applications can be found to empirically investigate the impact of off-farm income on food expenditure on rural HHs, the climatic impacts across agricultural crop yield distribution, the effect of agricultural extension on farm yields and how subsidies policies affect rural livelihood (Mishra *et al.*, 2015; Sarker *et al.*, 2012; Barnwal and Kotani, 2013; Evenson and Mwabu, 2001; Lunduka *et al.*, 2013).

Given that in our case the data are available only for two years, the application of standard panel econometrics, such as fixed-effects models, is not straightforward in quantile models. The reason is based on the fact that standard demeaning transformation is a linear operator, "a property that is not shared by conditional quantiles" (Abrevaja & Dahl, 2008, page 381). When T is small (i.e.. T<5), a robust method for model identification is even more complicated and still constitutes an empirical issue (see, for instance, Abrevaya, 2001; Koenker & Hallock, 2001; Chernozhukov, 2005 and Canay, 2011 among others). Given this information, we prefer a more cautious and robust approach by employing a pooled estimator which includes time dummies with standard errors clustered at the HH level (when we specify the model at the plot level, i.e. agricultural production) and at the EA level (when the data are aggregated at the HH level, i.e. welfare outcomes). The quantile model is estimated by conditioning the set of outcome variables (agricultural production, total consumption and calories per day) to ten sections of the distribution (deciles) in order to fully capture potential non-linear effects. The production function follows the approach by Chavas & Di Falco (2012) in which the dependent variable includes information on a main crop (the most cultivated one), and the presence of other minor crops cultivated on the same plot enters in the production function as inputs. Accordingly, the production function is:

$$(1)\ \ y_i = \alpha + y_m \gamma + \chi_i' + \varepsilon_i$$

with y_m a vector of productivity of m minor crops and χ is a vector of other direct agricultural inputs (i.e. fertilizer, pesticides, labor). This framework presents interesting features to our research purposes, by overcoming the construction of an aggregate index of productivity which could overestimate the contribution of single crops, and the lack of considering the complementarity in productivity of crops cultivated on the same plot (present if estimating separate production function for each crop). Moreover, it accounts for the crop pattern and crop diversification on a single plot basis.

A2 - Endogenous switching regression model

Since we want to investigate under what circumstances and constraints does the adoption of certain agricultural practices become effective means of reducing soil loss at the plot level, a counterfactual scenario of the potential result achievable in the opposite case of the observed individual behavior is required. This can be assessed empirically by utilizing conditional expectations from an endogenous switching regression model (ESR). The ESR analyses the binary adoption decision, and the implications it has on soil loss in a two-stage framework. The use of the ESR to evaluate the practices adoption in agriculture is quite diffused (Alene and Manyong, 2007; Noltze *et al.*, 2013; Abdulai and Huffman, 2014; Cavatassi *et al.*, 2011). In fact, the adoption decision, in a context of cross sectional analysis and without a randomized controlled experiment, might suffer of sample selection and endogeneity bias. Sample selection bias refers to a case where the voluntary decision to adopt is observed only by a restricted, non-random sample. The adoption status may be endogenous when the decision to adopt or not adopt is correlated with unobservable factors that affect the outcome variables. The failure to control for this correlation yields an estimated downward biased adoption effect on outcomes. These factors are unknown to researchers, but accounted for in farmers' expectations, affecting both the decision to adopt these practices and the outcome variables. Moreover, since soil loss gap between adopters and non-adopters is assumed to be systematic, two different outcome equations are estimated in the ESR. The covariates are assumed to have different impacts on the two groups of farmers while a pooled sample would have considered the difference between groups as just intercept shifters. Therefore, with an ESR model, endogeneity and sample-selection (Hausman, 1978; Heckman, 1979) are both taken into account. The econometric specification is as follows:

$$(2)\ \delta^* = \alpha'(y_A - y_{NA}) + Z'\gamma + \varepsilon$$

$$\begin{cases} \delta = 0 \text{ if } \delta^* \leq 0 \\ \delta = 1 \text{ if } \delta^* > 0 \end{cases}$$

Equations (2) and (3) are the specification of a probit model for the dichotomous adoption decision (criterion function) in the first stage (Maddala, 1983). δ^* is the latent variable that determines if a farmer is an agricultural practice adopter or not, and is based on the farmers' expectations regarding the relative performance of the practices with respect to non-adoption, expressed in terms of an outcome variable y which is the soil loss; δ^* is not observable but we observe δ, which is the adoption dummy; Z' is a vector of covariates that are relevant for the adoption decisions; α and y are unknown parameters vectors to be estimated and ε is a random disturbance term with zero mean and σ^2 variance.

Equation 3 and 4 represent the regime equations, in the second stage, that we observe conditional to adoption decisions made at the first stage:

$$(3)\ y_{NA} = \varphi'\beta_{NA} + \eta \text{ if } \delta = 0$$

$$(4)\ y_A = \varphi\ \beta_A + \epsilon \text{ if } \delta = 1\ ,$$

where φ' is a vector of covariates that affects y and may overlap with Z', but with the caution, for the model identification purpose, to have at least one instrument in the criterion equation that is not in the regime equations; β_A and β_{NA} are vectors of parameters to be estimated, ϵ and η are random disturbances terms with zero mean and σ^2_ϵ and σ^2_η variance. The covariance matrix is:

$$\sum(\varepsilon, \epsilon, \eta) = \begin{vmatrix} \sigma_{\epsilon}^{2} & \sigma_{\eta\varepsilon} & \sigma_{\epsilon\varepsilon} \\ \sigma_{\eta\epsilon} & \sigma_{\eta}^{2} & \sigma_{\eta\varepsilon} \\ \sigma_{\epsilon\varepsilon} & \sigma_{\eta\varepsilon} & \sigma_{\varepsilon}^{2} \end{vmatrix},$$

where σ_{ε} equals 1 since α and y are estimable only up to a scale factor (Greene, 2008). Moreover, $\sigma_{\eta\varepsilon} = 0$ because it is not possible to observe adoption and non-adoption outcomes (Maddala and Nelson, 1975). Estimation of the covariance terms can provide a test for the endogeneity through the significance of the following correlation coefficients:

$$\rho_{\epsilon\varepsilon} = \sigma_{\epsilon\varepsilon}/\sigma_{\epsilon}\sigma_{\varepsilon}, \rho_{\eta\varepsilon} = \sigma_{\eta\varepsilon}/\sigma_{\eta}\sigma_{\varepsilon},$$

These correlations have also an economic interpretation that are explained in the description of results. The expected values of the truncated errors are equal to:

$$(7) \quad E(\eta|\delta = 0) = -\sigma_{\eta\varepsilon}\lambda_{\eta} = -\sigma_{\eta\varepsilon}\frac{f(\frac{\xi}{\sigma\varepsilon})}{1 - F(\frac{\xi}{\sigma\varepsilon})}$$

$$(8) \quad E(\epsilon|\delta = 1) = \sigma_{\epsilon\varepsilon}\lambda_{\epsilon} = \sigma_{\epsilon\varepsilon}\frac{f(\frac{\xi}{\sigma\varepsilon})}{F(\frac{\xi}{\sigma\varepsilon})}$$

where λ_{ϵ} and λ_{η} are the Inverse Mill Ratios estimated at $\xi = \alpha'(y_{MV} - y_{LL}) + z'y$ and f and F are, respectively, the density and the cumulative distribution function.

As explained in Lokshin and Sajaia (2004), the ESR can efficiently be estimated with the full information maximum likelihood (FIML) approach, ensuring the simultaneous estimation of the probit model and regime equations with consistent standard error.

The conditional expectations from the ESR can be used to estimate the average treatment effects (ATE) of the counterfactual scenario for both the groups. Expectations conditional to adoption decision are estimated as follows (Di Falco *et al.*, 2011):

$$(9) \quad E(y_{A}|\delta = 1) = \varphi'\beta_{A} + \sigma_{\epsilon\varepsilon}\lambda_{\epsilon}$$

$$(10) \quad E(y_{NA}|\delta = 1) = \varphi'\beta_{NA} + \sigma_{\eta\varepsilon}\lambda_{\epsilon}$$

$$(11) \quad E(y_{A}|\delta = 0) = \varphi'\beta_{A} + \sigma_{\epsilon\varepsilon}\lambda_{\eta}$$

$$(12) \quad E(y_{NA}|\delta = 0) = \varphi'\beta_{A} + \sigma_{\eta\varepsilon}\lambda_{\eta}$$

Equations (10) and (13) are the actual outcome expectations conditional to the adoption status chosen by farmers. These represent the expected soil loss of adopters when they adopt and the non-adopters outcome when they do not adopt. Equations (11) and (12) evaluate the outcomes in the counterfactual case that adopters did not adopt and that non-adopters adopted thereby providing a measure of the relative performance of the status for which the farmer has opted. Thus, the ATE of adoption on adopters (TT) and the ATE of adoption on non-adopters (TU) are equal to:

$$(13) \quad TT = E(y_{A}|\delta = 1) - E(y_{NA}|\delta = 1) = \varphi'(\beta_{A} - \beta_{NA}) + (\sigma_{\epsilon\varepsilon} - \sigma_{\eta\varepsilon})\lambda_{\epsilon}$$

$$(14)\quad TU = E(y_A \mid \delta = 0) - E(y_{NA} \mid \delta = 0) = \varphi'(\beta_A - \beta_{NA}) + (\sigma_{\epsilon\varepsilon} - \sigma_{\eta\varepsilon})\lambda_{\epsilon}$$

A3 - Seemingly Unrelated Regression model

The impact of agricultural practices in mitigating nutrient loss is estimated by means of seemingly unrelated equations (SUR). The main point in using this approach is that it allows both the same set of drivers to impact different outcome variables while correlating the error terms of each equation. Since the level of different nutrients in the soil are interrelated and influenced by the same set of agricultural practices (likely simultaneously) applied by farmers and by the same agro-ecological conditions, the SUR model represents a suitable empirical strategy in this context (Nguyen *et al.*, 2017, Asfaw *et al.*, 2018).

A4 - CGE model

To evaluate the macroeconomic impacts stemming from the productivity loss of soil erosion we employed the standard Gtap general equilibrium model (Hertel, 1997) and the Gtap 9 database (Aguiar *et al.*, 2016). The model includes representative firms and HHs and production factors. This category of models (also called top-down) allows for the analysis of the effects of energy and climate policies on specific sectors and its propagation to the entire economic system. In fact, the model reconciles the various economic sectors (on a national and international scale) through input-output relations.

A41 - The Supply side

Industries are "typically" modelled through a representative cost-minimizing firm, taking input prices as given. In turn, output prices are given by average production costs.

Figure 1 illustrates the nested production function of each representative firm (that coincides with the concept of sector) within the model. Each node in the tree combines single or composite factors of production in a constant elasticity of substitution (CES) production function. All sectors use primary factors such as labour and capital-energy, and intermediate inputs. In some sectors (fossil fuel extraction industries and fishery), primary factors include natural resources, (e.g. fossil fuels or fish), in some other (agricultural sectors) land. The nested production structure depicted is the same across all sectors, and diversity in production processes as well as technologies are captured through sector-specific productivity and substitution elasticity parameters.

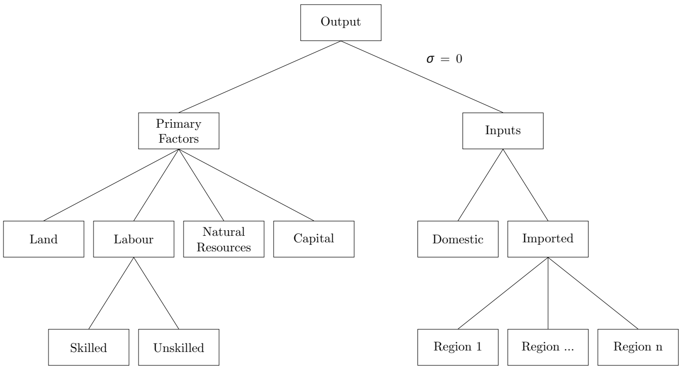

Figure 32: Supply structure of the Gtap model

A42 - The Demand side

In each region, a representative utility maximizing household receives income, originated by the service value of national primary factors (natural resources, land, labour, and capital), that she/he owns and sells to the firms. Capital and labour are perfectly mobile domestically but immobile internationally (note however that investment is mobile). Land and natural resources, on the other hand, are industry-specific. The regional income is used to finance three classes of expenditure: aggregate household consumption, public consumption and savings. These expenditure shares are generally fixed, which amounts to saying that the top-level utility function has a Cobb-Douglas specification. Also notice that savings generate utility and this can be interpreted as a reduced-form of intertemporal utility.

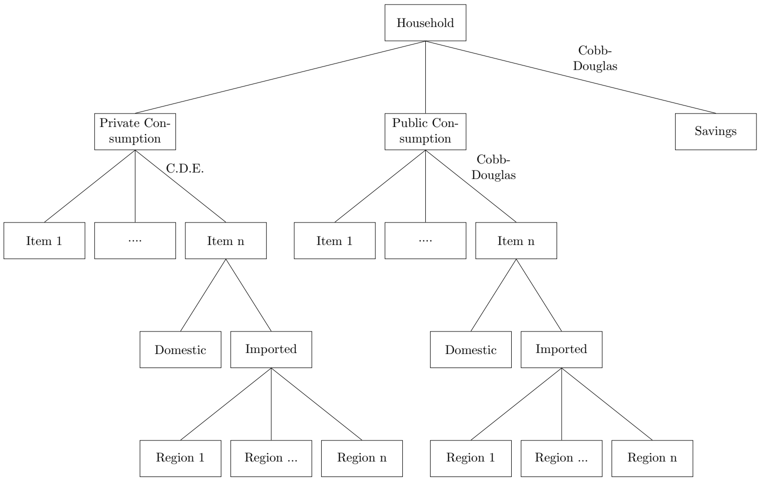

Figure 33: Demand structure of the Gtap model

Both private and public sector consumption are addressed for all commodities produced by each firm/sector. Public consumption is split into a series of alternative consumption commodities (item 1 to item n in figure 2), again according to a Cobb-Douglas specification. However, almost all public expenditure is actually concentrated in the specific sector of Non-market Services, including education, defence and health.

A43 - Modelling soil loss productivity shock

We follow the approach of Panagos *et al.* 2018 to model the crop productivity loss related to soil erosion as an exogenous input into the model. Land is one of the primary factors of the model along with labour, capital and other intermediates (e.g. fertilizers) and is used by a representative farmer to produce the crop commodity. The model employs a constant elasticity of substitution function that combines land (LA), labour (L) and capital (K) and determines the value added of each sector (see equation no. 15).

$$(15)\quad VA_{i,r} = \left(\alpha_{i,r}\, LA_{i,r}^{\frac{\sigma_i - 1}{\sigma_i}} + \gamma_{i,r}\, K_{i,r}^{\frac{\sigma_i - 1}{\sigma_i}} + \delta_{i,r}\, L_{i,r}^{\frac{\sigma_i - 1}{\sigma_i}}\right)^{\frac{\sigma_i}{\sigma - 1}}$$

The $\alpha_{i,r}$, $\gamma_{i,r}$ and $\delta_{i,r}$ are exogenous variables that represent the degree of substitutability of the factors. For land, the $\alpha_{i,r}$ is used to simulate a change in land productivity according to the effect of soil loss.

14 Appendix B - Results

B1 - Impact of nutrient loss on production by decile

	Deciles								
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
agehead	0.001	0.000	-0.000	0.000	0.001	0.001	0.002**	0.002***	0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
female headed hh	-0.111***	-0.101***	-0.116***	-0.109***	-0.101***	-0.111***	-0.107***	-0.100***	-0.134***
	(0.043)	(0.033)	(0.027)	(0.025)	(0.025)	(0.023)	(0.024)	(0.025)	(0.030)
educave	0.031***	0.027***	0.028***	0.031***	0.030***	0.030***	0.035***	0.035***	0.035***
	(0.008)	(0.005)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.006)
hhsize	0.003	0.006	0.004	0.014***	0.015***	0.015***	0.014***	0.017***	0.022***
	(0.008)	(0.006)	(0.005)	(0.005)	(0.004)	(0.004)	(0.004)	(0.005)	(0.005)
disturban	-0.030***	-0.027**	-0.027***	-0.031***	-0.029***	-0.033***	-0.030***	-0.023***	-0.023**
	(0.012)	(0.012)	(0.010)	(0.008)	(0.008)	(0.009)	(0.008)	(0.008)	(0.011)
plot_area	0.286***	0.274***	0.265***	0.283***	0.302***	0.307***	0.308***	0.327***	0.327***
	(0.025)	(0.024)	(0.018)	(0.018)	(0.018)	(0.019)	(0.015)	(0.014)	(0.023)
labor	0.151***	0.131***	0.115***	0.100***	0.095***	0.095***	0.088***	0.075***	0.076***
	(0.028)	(0.018)	(0.014)	(0.014)	(0.012)	(0.013)	(0.013)	(0.012)	(0.018)
fert1	0.124***	0.124***	0.118***	0.114***	0.105***	0.100***	0.096***	0.090***	0.076***
	(0.011)	(0.008)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)	(0.007)
fert2	0.119***	0.106***	0.107***	0.101***	0.098***	0.092***	0.089***	0.084***	0.079***
	(0.012)	(0.008)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.006)	(0.007)
fert3	0.082***	0.052***	0.082***	0.088***	0.101***	0.090***	0.080***	0.068***	0.074***
	(0.027)	(0.018)	(0.016)	(0.015)	(0.012)	(0.012)	(0.012)	(0.013)	(0.017)
fert4	0.102***	0.106***	0.106***	0.095***	0.084***	0.077***	0.076***	0.094***	0.081***
	(0.034)	(0.024)	(0.017)	(0.015)	(0.015)	(0.012)	(0.018)	(0.017)	(0.023)
organic_ fert	0.017*	0.015**	0.017***	0.012**	0.018***	0.021***	0.026***	0.031***	0.024***
	(0.009)	(0.007)	(0.005)	(0.006)	(0.005)	(0.006)	(0.006)	(0.005)	(0.006)
pesticides	-0.300***	0.013	0.067	0.093	0.156**	0.113	0.203***	0.154***	0.366
	(0.083)	(0.156)	(0.065)	(0.186)	(0.076)	(0.075)	(0.044)	(0.031)	(0.317)
seeds	0.196***	0.180***	0.172***	0.171***	0.177***	0.186***	0.177***	0.184***	0.150***
	(0.028)	(0.021)	(0.018)	(0.016)	(0.015)	(0.016)	(0.015)	(0.016)	(0.018)
MV	0.028	0.043	0.037	0.054**	0.059***	0.072***	0.100***	0.086***	0.104***
	(0.043)	(0.028)	(0.024)	(0.023)	(0.020)	(0.020)	(0.020)	(0.022)	(0.026)

D_ groundnut	-0.077	-0.056	-0.053	-0.043	-0.051	-0.058	-0.055	-0.062	-0.031
	(0.062)	(0.052)	(0.044)	(0.041)	(0.041)	(0.040)	(0.034)	(0.041)	(0.055)
D_other_ crops	0.008	-0.029	-0.058**	-0.064***	-0.061**	-0.047*	-0.047**	-0.053**	-0.052
	(0.042)	(0.035)	(0.027)	(0.024)	(0.025)	(0.025)	(0.023)	(0.025)	(0.034)
D_ legumes	0.193***	0.175***	0.156***	0.138***	0.153***	0.139***	0.114***	0.102***	0.106**
	(0.070)	(0.046)	(0.040)	(0.038)	(0.035)	(0.032)	(0.035)	(0.033)	(0.048)
s_r_spei	0.077	0.096**	0.057*	0.039	0.058**	0.047*	0.075***	0.070***	0.053
	(0.049)	(0.041)	(0.030)	(0.030)	(0.028)	(0.028)	(0.028)	(0.027)	(0.035)
s_d_spei	-0.361***	-0.283***	-0.272***	-0.260***	-0.268***	-0.237***	-0.231***	-0.203***	-0.186***
	(0.050)	(0.038)	(0.028)	(0.027)	(0.026)	(0.029)	(0.027)	(0.028)	(0.032)
p	-0.380*	-0.152	-0.227	-0.078	0.118	-0.054	0.009	0.217*	0.057
	(0.211)	(0.230)	(0.162)	(0.123)	(0.123)	(0.141)	(0.139)	(0.115)	(0.204)
n	-0.270**	-0.344***	-0.198**	-0.187***	-0.213***	-0.255***	-0.251***	-0.247***	-0.152*
	(0.119)	(0.097)	(0.083)	(0.065)	(0.075)	(0.071)	(0.068)	(0.069)	(0.086)
c	0.423**	0.179	0.175	0.168	0.106	0.008	0.002	-0.065	-0.020
	(0.193)	(0.160)	(0.130)	(0.102)	(0.129)	(0.119)	(0.109)	(0.107)	(0.143)
k	0.239	0.211*	0.193	0.176*	0.013	0.102	0.086	0.089	0.208*
	(0.216)	(0.126)	(0.118)	(0.100)	(0.080)	(0.087)	(0.110)	(0.084)	(0.115)
p:n	0.096**	0.037	0.061**	0.038	0.033	0.052**	0.039*	0.020	0.009
	(0.040)	(0.038)	(0.029)	(0.028)	(0.022)	(0.021)	(0.023)	(0.027)	(0.032)
c:n	-0.036	-0.004	-0.018	-0.014	-0.009	-0.002	0.003	0.014	0.007
	(0.024)	(0.021)	(0.018)	(0.014)	(0.017)	(0.016)	(0.015)	(0.014)	(0.021)
k:n	-0.003	0.015	-0.004	0.007	0.012	0.002	0.009	0.003	0.004
	(0.032)	(0.028)	(0.023)	(0.023)	(0.018)	(0.017)	(0.019)	(0.023)	(0.022)
p:c	-0.058*	-0.032	-0.037	-0.033	-0.049**	-0.037*	-0.036*	-0.048*	-0.017
	(0.035)	(0.034)	(0.027)	(0.026)	(0.020)	(0.021)	(0.021)	(0.025)	(0.027)
k:c	-0.030	-0.044	-0.016	-0.024	-0.003	-0.008	-0.012	-0.005	-0.024
	(0.037)	(0.031)	(0.025)	(0.023)	(0.018)	(0.018)	(0.021)	(0.023)	(0.024)
p:k	-0.009	-0.009	-0.020*	-0.020**	-0.025***	-0.032***	-0.032***	-0.028***	-0.023*
	(0.012)	(0.011)	(0.011)	(0.009)	(0.008)	(0.009)	(0.011)	(0.008)	(0.013)
Constant	4.485***	5.738***	5.626***	5.615***	6.158***	6.858***	6.860***	6.969***	6.747***
	(0.944)	(0.772)	(0.652)	(0.528)	(0.625)	(0.582)	(0.536)	(0.526)	(0.665)
N	9059								

Notes: Standard errors clustered at EA level are in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. Estimates include a dummy for 2013 year.

B2 - Impact of soil loss on per capita real consumption

	Deciles								
	(1) 0.10	(2) 0.20	(3) 0.30	(4) 0.40	(5) 0.50	(6) 0.60	(7) 0.70	(8) 0.80	(9) 0.90
agehead	-0.000	-0.001	-0.000	-0.001	-0.000	0.000	-0.000	-0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
femhead	-0.027	-0.064**	-0.059***	-0.057**	-0.077***	-0.103***	-0.094***	-0.089**	-0.070**
	(0.034)	(0.027)	(0.021)	(0.025)	(0.028)	(0.024)	(0.024)	(0.036)	(0.035)
educave	0.013***	0.008*	0.007**	0.006*	0.005	0.002	-0.005	-0.006*	-0.003
	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)	(0.004)	(0.005)
disturban	-0.039***	-0.036**	-0.047***	-0.052***	-0.054***	-0.060***	-0.058***	-0.058***	-0.061***
	(0.012)	(0.014)	(0.012)	(0.011)	(0.013)	(0.012)	(0.012)	(0.013)	(0.015)
plot_area	-0.007	-0.003	0.002	0.004	0.001	0.003	0.005	0.003	0.002
	(0.005)	(0.003)	(0.003)	(0.003)	(0.005)	(0.003)	(0.003)	(0.004)	(0.005)
TLU	0.040*	0.024	-0.015	-0.035*	-0.029	-0.026	-0.048**	-0.064***	-0.053
	(0.024)	(0.026)	(0.021)	(0.020)	(0.023)	(0.022)	(0.021)	(0.024)	(0.036)
tech_endow	0.195***	0.221***	0.201***	0.187***	0.196***	0.197***	0.209***	0.225***	0.157***
	(0.025)	(0.023)	(0.020)	(0.022)	(0.020)	(0.022)	(0.025)	(0.029)	(0.032)
owner	0.098	-0.099	-0.099	-0.115	-0.165	-0.101	-0.173	-0.129	-0.042
	(0.294)	(0.207)	(0.261)	(0.154)	(0.164)	(0.139)	(0.229)	(0.280)	(0.129)
n_plot	0.025*	0.026**	0.017*	0.015	0.012	0.011	0.016*	-0.002	-0.014
	(0.014)	(0.010)	(0.009)	(0.009)	(0.011)	(0.011)	(0.009)	(0.011)	(0.013)
spfarm2	0.093***	0.087***	0.083***	0.090***	0.087***	0.062***	0.040**	0.024	0.022
	(0.023)	(0.023)	(0.018)	(0.018)	(0.018)	(0.019)	(0.021)	(0.022)	(0.028)
s_r_spei	-0.074**	-0.071**	-0.054*	-0.053*	-0.033	-0.038	-0.036	-0.025	-0.028
	(0.031)	(0.033)	(0.029)	(0.028)	(0.030)	(0.030)	(0.031)	(0.032)	(0.037)
s_d_spei	-0.126***	-0.087**	-0.047	-0.036	-0.047	-0.034	-0.030	-0.035	0.006
	(0.037)	(0.037)	(0.031)	(0.032)	(0.033)	(0.034)	(0.034)	(0.036)	(0.042)
D_crop_maize	0.235**	0.176	0.176	0.205**	0.157*	0.173**	0.147	0.039	-0.047
	(0.118)	(0.171)	(0.119)	(0.081)	(0.087)	(0.078)	(0.167)	(0.099)	(0.078)
D_crop_groundnut	0.048*	0.046*	0.062***	0.077***	0.089***	0.098***	0.086***	0.120***	0.095***
	(0.025)	(0.024)	(0.023)	(0.024)	(0.025)	(0.024)	(0.025)	(0.028)	(0.033)
D_crop_legumes	-0.022	0.004	-0.014	0.005	-0.006	-0.006	-0.019	0.013	-0.034
	(0.033)	(0.039)	(0.035)	(0.036)	(0.040)	(0.034)	(0.040)	(0.052)	(0.040)
D_crop_other	-0.009	-0.013	-0.002	-0.001	-0.015	-0.014	-0.034*	-0.039*	-0.042
	(0.025)	(0.024)	(0.020)	(0.021)	(0.020)	(0.021)	(0.021)	(0.024)	(0.029)
parliament	0.071	0.082**	0.074**	0.054	0.043	0.037	0.024	0.040	0.059
	(0.044)	(0.042)	(0.032)	(0.034)	(0.040)	(0.046)	(0.041)	(0.056)	(0.059)

infraindex	0.085***	0.071***	0.078***	0.085***	0.072***	0.067***	0.085***	0.072***	0.130***
	(0.011)	(0.016)	(0.017)	(0.011)	(0.011)	(0.016)	(0.011)	(0.012)	(0.016)
soil_loss	-0.103**	-0.111*	-0.105*	-0.103*	-0.104*	-0.086	-0.075	0.062	0.046
	(0.052)	(0.068)	(0.065)	(0.055)	(0.056)	(0.075)	(0.075)	(0.076)	(0.069)
wealth	0.158***	0.175***	0.187***	0.185***	0.185***	0.191***	0.187***	0.175***	0.157***
	(0.011)	(0.009)	(0.010)	(0.009)	(0.009)	(0.011)	(0.008)	(0.010)	(0.013)
femhead:-soil_loss	-0.017	-0.044**	-0.049***	-0.047**	-0.057***	-0.093***	-0.084***	-0.099	-0.057
	(0.024)	(0.017)	(0.011)	(0.015)	(0.018)	(0.014)	(0.014)	(0.066)	(0.055)
Constant	9.722***	10.271***	10.353***	10.628***	10.859***	10.853***	11.070***	11.270***	11.533***
	(0.301)	(0.223)	(0.281)	(0.205)	(0.210)	(0.194)	(0.219)	(0.302)	(0.230)
N	7376								

Notes: Standard errors clustered at EA level are in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01. Estimates include a dummy for 2013 year.

B3 - Impact of soil loss on per capita caloric intake

	Deciles								
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
agehead	0.001	0.002**	0.001*	0.001*	0.001*	0.001***	0.001***	0.001*	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)	(0.001)
femhead	0.450	-0.023	0.108	0.116	0.084	0.079	0.206	-0.022	0.010
	(0.562)	(0.406)	(0.230)	(0.198)	(0.187)	(0.194)	(0.170)	(0.187)	(0.457)
educave	0.006	0.010***	0.009***	0.012***	0.009***	0.007***	0.005**	0.005*	0.004
	(0.006)	(0.004)	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)
hhsize	-0.045***	-0.050***	-0.063***	-0.077***	-0.087***	-0.093***	-0.091***	-0.084***	-0.079***
	(0.009)	(0.005)	(0.003)	(0.003)	(0.003)	(0.004)	(0.005)	(0.004)	(0.005)
disturban	0.002	0.008	-0.001	-0.005	-0.004	-0.005	-0.005	0.001	0.014
	(0.012)	(0.010)	(0.006)	(0.006)	(0.006)	(0.006)	(0.005)	(0.007)	(0.010)
plot_area	-0.006	0.002	0.006*	0.004	0.001	-0.001	0.000	0.000	-0.005
	(0.011)	(0.005)	(0.003)	(0.004)	(0.004)	(0.003)	(0.002)	(0.003)	(0.004)
non techn agri asset	0.022***	0.012***	0.010***	0.012***	0.015***	0.014***	0.013***	0.015***	0.016***
	(0.005)	(0.004)	(0.003)	(0.003)	(0.002)	(0.002)	(0.003)	(0.004)	(0.004)
techn asset	0.027	-0.025	0.039	0.014	0.009	0.061	0.087***	0.039	0.102
	(0.102)	(0.035)	(0.066)	(0.029)	(0.036)	(0.107)	(0.034)	(0.034)	(0.109)
TLU	0.017	0.009**	0.003	0.000	0.002	-0.002	-0.002	-0.002	0.005
	(0.011)	(0.004)	(0.004)	(0.006)	(0.004)	(0.004)	(0.008)	(0.009)	(0.013)
tech_endow	0.172***	0.118***	0.108***	0.096***	0.086***	0.083***	0.085***	0.075***	0.054**
	(0.049)	(0.030)	(0.021)	(0.018)	(0.015)	(0.014)	(0.015)	(0.019)	(0.027)
owner	0.429	0.450	0.280**	0.022	0.026	0.122	0.167	0.112	0.453
	(0.268)	(0.274)	(0.130)	(0.155)	(0.099)	(0.100)	(0.124)	(0.189)	(0.488)

s_r_spei	-0.141***	-0.093**	-0.058**	-0.048**	-0.031	-0.021	-0.018	-0.032	-0.048
	(0.050)	(0.036)	(0.025)	(0.021)	(0.022)	(0.021)	(0.024)	(0.025)	(0.030)
s_d_spei	-0.021	-0.006	0.003	-0.029	-0.036*	-0.050***	-0.035*	-0.047*	-0.078**
	(0.052)	(0.036)	(0.024)	(0.021)	(0.020)	(0.019)	(0.021)	(0.025)	(0.034)
labor	-0.004	-0.006	-0.005*	-0.006***	-0.005***	-0.004**	-0.004**	-0.006**	-0.006**
	(0.007)	(0.004)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
fert1	0.007	0.004*	0.004*	0.004***	0.005***	0.003**	0.003*	0.004**	0.003
	(0.005)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
fert2	0.006	0.007***	0.006***	0.005***	0.005***	0.005***	0.004***	0.002	0.002
	(0.004)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
fert3	0.007	0.004	0.004	0.007**	0.007**	0.008**	0.008**	0.010**	0.006
	(0.010)	(0.004)	(0.003)	(0.003)	(0.003)	(0.003)	(0.004)	(0.004)	(0.004)
fert4	-0.006	-0.002	0.004	0.003	0.006*	0.005	0.006	0.006	0.009*
	(0.024)	(0.007)	(0.004)	(0.004)	(0.004)	(0.003)	(0.004)	(0.004)	(0.005)
organic_fert	-0.002	0.001	0.000	0.001	0.001	0.002*	0.002*	0.003***	0.001
	(0.004)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.003)
pesticides	-0.086*	-0.012	-0.015**	-0.012	-0.013	-0.002	0.003	-0.009	-0.024
	(0.047)	(0.064)	(0.007)	(0.016)	(0.016)	(0.031)	(0.023)	(0.017)	(0.027)
seeds	0.003	0.011*	0.009**	0.012***	0.008**	0.007**	0.008**	0.009**	0.009
	(0.012)	(0.006)	(0.004)	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)	(0.006)
maize	0.078	-0.021	0.023	-0.011	-0.029	-0.075	-0.102**	-0.119***	-0.390
	(0.129)	(0.058)	(0.038)	(0.043)	(0.047)	(0.054)	(0.050)	(0.042)	(0.369)
groundnut	0.032	0.031	0.029	0.022	0.029	0.022	0.022	0.027	0.030
	(0.041)	(0.026)	(0.018)	(0.018)	(0.017)	(0.017)	(0.018)	(0.024)	(0.033)
beans	-0.032	-0.000	0.009	-0.014	-0.018	-0.006	0.000	-0.012	-0.016
	(0.105)	(0.036)	(0.026)	(0.023)	(0.023)	(0.022)	(0.024)	(0.031)	(0.046)
other_crops	-0.013	0.003	0.012	0.013	0.007	-0.005	-0.011	-0.009	-0.014
	(0.041)	(0.024)	(0.018)	(0.016)	(0.015)	(0.015)	(0.018)	(0.021)	(0.027)
Food progr. received	0.069	0.044	0.049**	0.040*	0.035*	0.002	-0.001	0.002	-0.033
	(0.052)	(0.035)	(0.022)	(0.023)	(0.020)	(0.019)	(0.020)	(0.028)	(0.037)
infraindex	0.031	0.023**	0.019	0.019**	0.016**	0.024***	0.021***	0.013*	0.012
	(0.021)	(0.010)	(0.012)	(0.008)	(0.008)	(0.009)	(0.006)	(0.007)	(0.012)
soil_loss	-0.143*	-0.125**	-0.119**	-0.115*	-0.114**	-0.105*	-0.084	-0.068	-0.052
	(0.067)	(0.062)	(0.060)	(0.065)	(0.061)	(0.052)	(0.067)	(0.043)	(0.049)
soil_loss:femhead	-0.060*	-0.042**	-0.024**	-0.021*	-0.020***	-0.020***	-0.018	0.006	0.002
	(0.035)	(0.022)	(0.011)	(0.011)	(0.007)	(0.006)	(0.018)	(0.020)	(0.049)
Constant	5.849***	6.555***	7.107***	7.560***	7.799***	8.000***	7.970***	8.282***	8.585***
	(0.690)	(0.397)	(0.229)	(0.243)	(0.191)	(0.186)	(0.197)	(0.289)	(0.584)
N	7376								

Notes: Standard errors clustered at EA level are in parentheses, *p < 0.1, **p < 0.05, ***p < 0.01. Estimates include dummies for AEZs, interactions of AEZs with the soil loss measures and year 2013.

B4 - Impact of anti-erosion practices on soil loss (ESR) – other covariates

	Dep. variables: soil loss		
	Adopters	Non-adopters	Select (S_HH=1)
agehead	-0.000	0.001	-0.001
	(0.001)	(0.001)	(0.001)
femhead	-0.066**	0.091***	-0.076***
	(0.028)	(0.034)	(0.028)
educave	-0.007	0.003	-0.006
	(0.005)	(0.006)	(0.005)
hhsize	0.012**	-0.004	0.010**
	(0.005)	(0.006)	(0.005)
disturban	-0.015*	0.079***	-0.040***
	(0.008)	(0.010)	(0.008)
wealth	0.004	0.011	0.005
	(0.011)	(0.014)	(0.011)
infraindex	-0.015	0.044**	-0.021
	(0.015)	(0.018)	(0.015)
owner	0.708*	2.561***	2.161***
	(0.363)	(0.265)	(0.290)
plot_area	0.033**	-0.041**	0.046***
	(0.016)	(0.020)	(0.016)
MV	0.022	-0.021	0.013
	(0.023)	(0.028)	(0.023)
s_r_spei	-0.028	0.172***	-0.103***
	(0.030)	(0.036)	(0.029)
s_d_spei	0.202***	0.152***	0.033
	(0.029)	(0.035)	(0.029)
tech_endow			0.031***
			(0.011)
Constant	9.138***	7.528***	1.999***
	(0.372)	(0.282)	(0.301)

lnsigma	0.039***	0.159***	
	(0.011)	(0.015)	
rho	2.800***	-2.748***	
	(0.085)	(0.063)	
N	9293		

Standard errors clustered at EA level in parentheses. * p < 0.1, ** p < 0.05, *** p < 0.0. The estimates include dummies for AEZs and year 2013.

B5 - Impact of practices on nutrient loss (SUR)

	(1)	(2)	(3)	(4)
	l_p_grams	l_n_grams	l_oc_grams	l_k_grams
labor	-0.160**	-0.029	-0.013	-0.285***
	(0.065)	(0.050)	(0.048)	(0.087)
fert1	-0.092***	0.033*	-0.030	-0.122***
	(0.024)	(0.019)	(0.018)	(0.033)
fert2	-0.146***	0.038*	-0.071***	-0.133***
	(0.025)	(0.020)	(0.019)	(0.034)
fert3	0.310***	-0.178***	0.168***	0.515***
	(0.065)	(0.050)	(0.049)	(0.087)
fert4	-0.079	-0.012	0.046	-0.078
	(0.080)	(0.062)	(0.060)	(0.107)
organic_fert	0.026	0.018	0.007	0.008
	(0.033)	(0.025)	(0.024)	(0.044)
pesticides	-0.392**	-0.099	-0.013	-0.442**
	(0.160)	(0.124)	(0.119)	(0.214)
labor^2	0.017***	-0.002	-0.003	0.028***
	(0.007)	(0.005)	(0.005)	(0.009)
fert1^2	0.023***	-0.004	0.005*	0.034***
	(0.004)	(0.003)	(0.003)	(0.006)
fert2^2	0.029***	0.010***	0.014***	0.039***
	(0.005)	(0.004)	(0.003)	(0.006)
fert3^2	-0.041***	0.041***	-0.035***	-0.074***
	(0.014)	(0.011)	(0.010)	(0.018)

fert4^2	0.018	0.002	-0.008	0.018
	(0.015)	(0.011)	(0.011)	(0.020)
organic_fert^2	-0.006	-0.003	-0.002	-0.001
	(0.005)	(0.004)	(0.004)	(0.007)
pesticides^2	0.073	0.033	0.011	0.097
	(0.048)	(0.037)	(0.036)	(0.064)
D_S_HH	-0.404***	-0.236***	0.215***	0.493***
	(0.027)	(0.021)	(0.020)	(0.036)
D_crop_legumes	-0.109***	-0.068**	0.073**	-0.201***
	(0.042)	(0.032)	(0.031)	(0.055)
fert1:fert2	-0.005***	-0.005***	-0.004***	-0.022***
	(0.002)	(0.001)	(0.001)	(0.002)
fert1:fert3	-0.016*	-0.014**	0.010*	-0.016
	(0.008)	(0.006)	(0.006)	(0.011)
fert2:fert3	-0.016	-0.001	0.002	-0.019
	(0.015)	(0.012)	(0.011)	(0.020)
D_fallow	0.143***	0.154***	-0.024	0.004
	(0.033)	(0.026)	(0.025)	(0.045)
Constant	3.670***	6.758***	6.881***	5.246***
	(0.166)	(0.128)	(0.124)	(0.222)
N	9255			

Standard errors, clustered at HH level, are in parentheses. Statistical significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Estimates include socio-economic controls and year and AEZ dummies (2013). Estimates include interaction between AEZ and fert1 and fert4; between fert1-fert4 and wealth endowement.

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The **Poverty-Environment Initiative (PEI)** Malawi of the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP) supports country-led efforts to mainstream poverty-environment linkages into national development planning and budgeting. PEI provides financial and technical assistance to government partners to set up institutional and capacity-strengthening programs and carry out activities to address the particular poverty-environment context. PEI is funded by the governments of Norway, Spain, Sweden, the United Kingdom, and the European Union and with core funding of UNDP and UNEP.

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The **Global Soil Partnership (GSP)** was established in December 2012 as a strong interactive partnership to promote sustainable soil management. It is a mechanism that fosters enhanced collaboration and synergy of efforts between all stakeholders, from land users through to policy makers. Its mandate is to improve governance of the planet's limited soil resources in order to promote the sustainable management of soils and guarantee healthy and productive soils for a food secure world, as well as support other essential ecosystem services. Awareness raising, advocacy, policy development and capacity development on soils, as well as relevant implementation in the field are among the main GSP activities.

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