The economic impact of soil and nutrient loss in Malawi

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1 Introduction

1.1 Background

Soil erosion is 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). Land degradation instead is a broader 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 process causing topsoil loss and land degradation (UNEP, 2015; Oldeman et al., 1991).

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

Although it is a natural event, it is usually caused or increased by human activities that remove vegetation cover, such as deforestation, overgrazing, and ploughing. Drivers of soil and nutrient loss can be distinguished by proximate and underlying. Proximate drivers are the ones that impact directly the land ecosystem: 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 include: land tenure, poverty, population density and weak policy/regulatory environment in the agricultural and environmental sectors (Nkonya et al., 2016).

Given the size of the agriculture sector in the Malawian economy, soil and nutrient loss represents a major limitation to the overall economic development. It results into loss of agricultural productivity, increased expenditure on fertilizers, and a general decline in profitability of crop production. However, performing a search on Google Scholar looking for "soil erosion" produces about 1,030,000 results (10 May 2018), while looking for the topic "soil erosion costs" only shows 3,930 publications (a share of 0.4%). At the same time, a search on "soil nutrient loss" returns 2,360 results (only 642 if we make a combined search of the terms "costs" and "soil nutrient loss"). These low percentages show 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.

The aim of this work is to feel this gap and analyse the economic impact of both soil and nutrient loss in Malawi with new country-representative data on soil loss and nutrient 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 and then, it identifies best practices to mitigate the soil loss.

This research innovates on several aspects: both proximate and underlying drivers of soil loss are accounted for; the economic impact of the loss of nutrients on is also considered; state-of-the-art climatic indicators (SPEI and SPI) are employed to identify climate anomalies.

The work proceeds as follows. The relevant literature regarding the soil loss phenomenon, the soil conservation measures and the main methodologies adopted to quantify the impact are presented in section 2. Section 3 describes the empirical models employed to estimate the costs of agricultural productivity loss due to soil erosion and nutrient loss. Section 4 present the results.

2 Literature review

2.1 Land degradation and soil erosion

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 determines 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 is an event common to all over the world but has different intensity and scope due to 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. Although it is a natural event, it is usually 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 water's evaporation (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 yields (Jones, et al., 2013).

Agricultural and management practices such as poorly managed irrigation and over-exploitation can lead to the loss of soil nutrients and result in soil and land degradation, while the extreme use of agrochemicals can pollute soils and degrade the land (UNCCD, 2012). Also the excessive use of heavy machinery and repeated trampling by grazing animals can determine 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).

Drivers of land degradation are manifold (Lambin and Geist 2006). According to Nkonya et al. (2016), they can be distinguished in two classes: proximate and underlying. Proximate drivers are the ones that impact directly the land ecosystem. 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 induce salinization of the soil (Wale and Dejenie, 2013). Deforestation is often correlated to 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.

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

2.2 Soil loss in Malawi

Soil loss is a major threat to the agricultural development in Malawi and, given the size of the agricultural sector in the Malawian economy, it also represents a major limitation to the overall economic development of the country. Soil loss reduces the cultivable soil depth but it also takes away the fertile soils from the farmlands. The net effect is loss of 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 not entirely good for the country that depends on the soil for agricultural productivity. There is a potential for huge economic losses associated by the increasing soil loss trends. 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 in the country is necessary to underscore 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 pots. Amphlett (1984) performed soil loss studies in different plots in south Malawi (Bvumbwe, Mindawo, and Mphezo basins) and found seasonal soil loss rate 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 km2 grid cells to map Erosion Hazards Units for the entire country. Then for each grid they convert the EHU into soil loss finding 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 yields. 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 of 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 taken with care, as pointed out in Yaron et al. (2011) given the methodology used (secondary data analysis) and Malawi's diversity in terms of erosion characteristics, the strength of the study is 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 at assessing "the potential environmental impacts of increased smallholder production of burley tobacco" in terms of soil erosion, water quality, and deforestation. Liberalization of burley tobacco was pursued to increase smallholder participation in the cultivation of a remunerative crop. However, burley is also an extremely erosive 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 could be controlled) and farmer's 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 in the range 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 of 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 determines a depletion of soil nutrients that could alter the balance of the various components 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 was made 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 these data were linked with 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. In this latter scenario, farmers would use more fertilizers (49 vs. 15kg per hectare) but they would also double the yield (1.5 tons per hectare) compared to what farmers were getting under the current practice (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 finding was that under current smallholder soil management practice, annual loss of productive value of land was US$21 per hectare. This was 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 survey income data from the Integrated Household Survey (IHS2), they investigate how changes in agricultural productivity affect poverty. The IFPRI model estimated that achieving 6% growth in agricultural yields during 2005-2015, would increase the overall GDP growth rate from 3.2% to 4.8% per year, leading to the proportion in poverty falling to 34.5% by 2015. This was considerably lower than the 47.0% poverty rate projected in the absence of the additional agricultural growth. The 6% agricultural yield growth resulted in an additional 1.88 million people being lifted above the poverty line 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 the downstream farmers.

Recently, Vargas and Omuto (2014) performed a soil loss assessment using the SLEMSA model with secondary data. They found an average national soil loss rates in 2014 of 29 t/ha/year. The areas with relatively high rates were the north and 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, severity of soil loss problems in Malawi in 2014 could be regarded to have been moderated 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 erosive rainfall characteristics.

2.3 Soil conservation measures

Sustainable Land Management (SLM) can provide many benefits and help farmers to cope with the global challenges of land degradation, climate change, food insecurity and poverty. Among SLM practices, Conservation Agriculture (CA) received increasing attention from the scientific community and international organizations. CA is a set of land management practices and is characterized by three different components: minimum tillage, permanent organic soil coverage and crop rotation/intercropping.

In Malawi, the first initiative to promote CA was introduced by the international non-governmental organization (NGO) Sasakawa Global 2000 (SG2000) in 1998. The programme promoted the adoption of minimum tillage providing the farmers herbicides and high amounts of fertilisers and generated significant yield improvements (Ito et al., 2007). Nevertheless, more recently, some studies questioned the benefits of the SG2000 model of promoting CA. Thierfelder et al. (2015) connected the maize yield improvement to the high-input package rather than to to the CA technologies. Other analyses emphasized the lack of sustainability and farmer involvement (Thierfelder et al., 2013).

Since then, the SG2000 approach has been widely replicated in Malawi mainly by NGOs, such as Total Land Care, Care Malawi, Concern Worldwide, World Vision International, Concern Universal and Sasakawa Global 2000. This determined the spread in the country of internationally funded programmes that were implemented without a nationally-developed strategy or technical guidelines casting confusion on the real meaning and scope of CA (Dougill et al. 2017). In 2013, this confusion led to the formation of the National Conservation Agriculture Task Force (NCATF) to promote coordination and lesson sharing (Ligowe et al., 2013).

The reasons to advocate CA are many: it has been reported to reduce soil degradation and improve yields but also profitability and income (Asfaw et al., 2014; Kaluzi et al., 2017).

Despite the benefits of CA and the support of 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 CA practices (Phiri et al., 2012; Dougill et al., 2017).

Ward et al. (2016) employ discrete choice experiments to study farmers' preferences for different practices of CA and assess willingness to adopt CA. Their findings suggest that despite many long-term agronomic benefits, some farmers are not willing to adopt CA without subsidies. Farmers perceive that CA practices interact with one another differently, sometimes complementing and sometimes degrading the benefits of the other practices. Farmers' preferences are a function of experiences with CA, such that current farm level practices influence willingness to adopt the full CA package. Further, exposure to various risks such as flooding and insect infestations often constrains adoption.

Lovo (2016) analyses the impact of tenure insecurity on the adoption of soil CA measures. Using a large plot dataset from Malawi, the analysis employs a linear probability model with household fixed effects and finds that tenure insecurity has a negative effect on soil conservation investments. Her findings suggest that future land reforms should deal with the informality of the land rental market and address the gap between users and owners of land created by existing customary practices.

Ortega et al. (2016) analyse how diversifying maize monocrop with legumes would help reducing a declining soil fertility. They employ choice experiments to examine farmers' preferences for groundnut, soybean, and pigeon pea intercropped with maize and explore barriers and drivers to adoption in Central and Southern Malawi. Overall, farmers significantly discount legume yields in favour of maize yields despite the additional benefits provided by legumes. Labour constraints and market access are important barriers to legume adoption. Results identify three types of farmers with varying preferences for grain yields, the largest group (48%) associated with strongly positive preference for both legume and maize grain yield, a medium-sized group (35%) that values only maize yield, and the smallest group (17%) having preferences only for legume yield. The medium group may be growing legumes for other benefits such as enhanced maize productivity, and the smallest group may be primarily subsistence producers. These findings suggest that uptake of legume maize intercrop systems might be improved if practitioners focus on legumes that have lower labour requirements and better marketability.

Ngwira et al. (2012) in a study for 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.

In another study Ngwira et al. (2012b) examines the effects of several CA practices on crop productivity, profitability and soil quality in two farming communities from 2005 to 2011 in Malawi. They found that CA systems increased maize yield, net return and soil quality compared with conventional practices. Application of the three principles of CA, i.e., minimum tillage, retention of crop residue as surface mulch and crop association appeared to be vital for these benefits.

Marenya et al. (2014) conduct choice experiments to examine the preferences of smallholder farmers in Malawi regarding alternative policy-based incentives to adopt conservation practices. Results show that almost no farmer opted to use traditional farming practices when confronted with cash payment, insurance contract, and/or fertilizer subsidy-based incentives for the adoption of conservation agriculture. Thus, the scope for such incentive programs is substantial once the full effects of these practices are taken into account.

A study by Thierfelder et al. (2013) analyses the relationship of soil quality to soil processes and ecosystem services. They examined the relationship of different soil quality variables with crop production in several cropping systems including no till. They found higher infiltration rates with CA practices of reduced tillage compared to conventional at several sites in Malawi; these differences were also reflected in higher yields though the effect differed by site and duration of practices.

Ricker-Gilbert et al. (2014) empirically verify Boserup's (1965) hypothesis that growing population leads to increased input use per unit of land and increased production per unit of land. As population grows, farmers will move away from labour saving practices like slash and burn agriculture and will increase labour and capital intensive practices such as inorganic fertilizer and hybrid seed which maximize output per unit of land. Their results seem to confirm the hypothesis showing 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).

Pittelkow et al. (2015) assessed the effectiveness of conservation agriculture practices on agriculture productivity. They performed a global meta-analysis from 610 studies and compare no-tillage with normal tillage practices in 63 countries, and for 48 crops. Their results show that no-till reduces yields but under certain conditions it can produce equivalent or greater yields than conventional tillage. In particular, when no-till is combined with the other two conservation agriculture principles of residue retention and crop rotation, its negative impacts are minimized.

2.4 Soil erosion models

According to Avwunudiogba (2014), a classification of existing Soil Erosion Models (SOM) can be made on the base of the spatial representation of the physical process. In this respect, we can distinguish between Lumped Parameter Models (LPMs) and Distributed Parameter Models (DPMs). Lumped models use unified areas, whereas distributed models differentiate areas into detailed spatial structures. Table 1 lists all the models along with acronyms, full name and type of model.

LPMs use averaging methodologies to combine the impacts of different spatial processes of a given area. The focus of most LPMs as RUSLE and SLEM was initially to estimate long term average annual soil erosion at the field scale. However, later in the 1970s the influences of agricultural management practices and soil erosion on water quality and soil productivity became a major concern (Avwunudiogba, 2014). This stimulated the development of a number of LPMs that included specific procedures for evaluating the impact of different agricultural practices on nutrient loss, ground water pollution, and crop productivity. The USLE model (Wischmeier and Smith, 1978), now RUSLE (Renard et al., 1991), is the most widely used LPM (Avwunudiogba, 2014). The RUSLE is an empirical equation for predicting long-term average soil erosion from agricultural fields under specific cropping and management practice (Renard et al., 1991). Because the RUSLE is an empirical equation, its application depends on field data and the equations are valid within the limit of data from which it was developed. Indeed, a major criticism of the model is that its rainfall erosion factor is not suited for capturing the level of erosion of intense precipitation events, which are common in the humid tropics.

In order to localize variables of the model and improve its parameterization Ewell and Stocking (1982) developed the SLEMSA model for use in tropical and subtropical regions. Both RUSLE and SLEMSA and similar LPMs are incapable of measuring sediment deposition. This implies that sediment removed by rainfall is implicitly assumed to be entirely lost from the field which is very unlikely to happen. In addition, nutrient and runoff is not estimated by the models. CREAMS, GLEAMS and EPIC models were formulated to cope with this shortcoming. While CREAMS evaluates the relative effects of agricultural practices on pollutants in surface runoff and in soil water (Knisel, 1980), GLEAMS, an extension of CREAMS, models the transfer of nutrients within the original zone (Leonard et al., 1995). EPIC measures quantitatively the impact of erosion on crop productivity (Williams et al., 1983). However, as Avwunudiogba (2014) points out, “these models have limited routing capabilities for application at the watershed scale”. Another important limitation is that soil, cultural, and conservation management practices are assumed to be spatially homogeneous, a condition very unlikely in many environments where conservation agriculture practices are being implemented.

In contrast to LPMs, DPMs aim at taking into account the variation in parameter values and erosion controls. They try to incorporate the spatial and temporal variations of the physical process. Examples of these models include WEPP, EUROSEM, MEDALUS, LISEM, and KINEROS. Others in this category include models with the capacity to simulate nutrient and agricultural chemicals loadings in runoff, e.g. GAMES, ANSWERS, and AGNPS. However, LPMs are very region specific and only few attempt to apply DPMs outside the environment in which they were developed.

In general, DPMs have the potential of predicting the spatial and temporal distribution of net soil loss and deposition for an entire hill slope for any length of time. They have a wider range of applicability due to inbuilt process-based sub-models for describing the physical processes affecting erosion, and WEPP in particular generates its own weather and climatic data using a stochastic weather generator (Tiwari et al., 2000).

Table 1: Soil erosion models

Model acronym/ Full name	**References**	**Comments**
1. USLE/RUSLE Universal/Revised Universal Soil Loss Equation	(Wischmeier and Smith 1978) (Renard et al. 1991)	LPM
2. SLEMSA Soil Loss Estimator Model for Southern Africa	(Stocking and Elwell 1973)	LPM,
3. CREAMS Chemical Runoff and Erosion from Agricultural Management System	(Knisel 1980)	LPM
4. GLEAMS Groundwater Loading Effects of Agricultural Management System	(Leonard et al. 1995) (Knisel and Turtola 2000)	LPM,
5. EPIC Erosion Productivity Impact Calculator	(Williams et al. 1983)	LPM
6. KYERMO Kentucky Erosion Model	(Hirschi and Barfield 1988)	DPM
7. WEPP Water Erosion Prediction Project	(Nearing et al. 1989) (Flanagan et al. 2007)	DPM
9. EROSION 2D/3D 2-D Rainfall Erosion Model	(Schmidt et al. 1999)	DPM
10. MADALUS Mediterranean Desertification and Land Use	(Kirkby et al. 1988)	DPM
11. GAMES Guelph Model for Evaluating the Effects of Agricultural Management Systems on Soil Erosion and Sedimentation	(Rudra et al. 1986)	DPM
12. EUROSEM European Soil Erosion Model	(Morgan et al. 1998)	DPM
13. LISEM Limburg Soil Erosion Model	(De Roo 1996, De Roo et al. 1996)	DPM
14. ANSWERS The Areal Nonpoint Source Watershed Environment Response Simulation	(Beasley et al. 1980)	DPM
15. SWAT Soil and Water Assessment Tool	Gassman, et al. 2007)	DPM

Source: Avwunudiogba (2014).

3 Methodology

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

This approach presents several 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 allow 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 national-macro level by weighting 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 household's welfare (e.g. consumption or broader measures of poverty). Consequently, while investigating the determinants of productivity requires an analysis at plot level to catch impacts of pure agronomic and climatic processes, the impacts on welfare is conducted at household (HH) level to account for the socio-economic context affecting the livelihood capacity of farmers.

3.1 Impact of soil loss on agricultural production

Quantile regression model

In order to evaluate how the soil loss affects the agricultural production and HH welfare, 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 in the population under scrutiny. Indeed, the soil loss can produce impacts that are sensitive to different classes of welfare distribution. 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 households, the climatic impacts across agricultural crop yield distribution, the effect of agricultural extension on farm yields and how subsidies policies drives 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 lies 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). In light of this, we prefer a more cautious and robust approach by employing a pooled estimator which includes time dummies with standard errors clustered at HH level (when we specify the model at plot level, i.e. agricultural production) and at EA level (when the data are aggregated at 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 productivity of other minor crops cultivated on the same plot enters in the production function as inputs. Accordingly, the production function is:

$$(1) \quad y_i = \alpha + y_m\gamma + x_i'\beta + \varepsilon_i$$

with y_m a vector of productivity of m minor crops and x 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 prod. function for each crop). Moreover, it accounts for the crop pattern and crop diversification on a single plot basis.

3.2 Impact of agricultural practices on soil loss

<u>*Endogenous switching regression model*</u>

Since we want to investigate under what circumstances and constraints does the adoption of certain agricultural practices become an effective means of reducing the soil loss at 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 the 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 and the outcome variables. Moreover, since the 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) $$\delta^{*} = \alpha'(y_A - y_{NA}) + z'\gamma + \varepsilon$$

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

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 in respect to the not 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 γ 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:

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

(5) $$y_A = \varphi'\beta_A + \epsilon\ if\ \delta = 1,$$

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_ϵ^2 and σ_η^2 variance. The covariance matrix is:

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

where σ_ε equals 1 since α and γ 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 contemporary (Maddala and Nelson, 1975). Estimation of the covariance terms can provide a test for the endogeneity through the significance of the following correlation coefficients:

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

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

(8) $$E(\eta|\delta=0)=-\sigma_{\eta\varepsilon}\lambda_{\eta}=-\sigma_{\eta\varepsilon}\frac{f\left(\frac{\xi}{\sigma_{\varepsilon}}\right)}{1-F\left(\frac{\xi}{\sigma_{\varepsilon}}\right)}$$

(9) $$E(\epsilon|\delta=1)=\sigma_{\epsilon\varepsilon}\lambda_{\epsilon}=\sigma_{\epsilon\varepsilon}\frac{f\left(\frac{\xi}{\sigma_{\varepsilon}}\right)}{F\left(\frac{\xi}{\sigma_{\varepsilon}}\right)}$$

where λ_{ϵ} and λ_{η} are the Inverse Mill Ratios estimated at $\xi=\alpha'(y_{MV}-y_{LL})+z'\gamma$ 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):

(10) $$E(y_A|\delta=1)=\varphi'\beta_A+\sigma_{\epsilon\varepsilon}\lambda_{\epsilon}$$

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

(12) $$E(y_A|\delta=0)=\varphi'\beta_A+\sigma_{\epsilon\varepsilon}\lambda_{\eta}$$

(13) $$E(y_{NA}|\delta=0)=\varphi'\beta_A+\sigma_{\eta\varepsilon}\lambda_{\eta}.$$

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:

(14) $$TT=E(y_A|\delta=1)-E(y_{NA}|\delta=1)=\varphi'(\beta_A-\beta_{NA})+(\sigma_{\epsilon\varepsilon}-\sigma_{\eta\varepsilon})\lambda_{\epsilon},$$

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

3.3 Impact of agricultural practices on nutrient loss

Seemingly Unrelated Regression model

The impact of agricultural practices in mitigating the 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).

3.4 Data

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

First, socio-economic data at household level are included in the Living Standards Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA) and in the Sustainable Agricultural Production Program (SAPP) data collected by Total Land Care. Second, the Soil Loss Assessment in Malawi (SLA) provides information at both plot and enumeration area (EA) level on measures of soil loss. Moreover, information on nutrients loss (potassium, phosphorous, carbon and nitrogen) and are also provided at plot level. Third, detailed climatic data are gathered from the Africa Rainfall Climatology version (ARC2) at EA detail.

The survey LSMS-ISA is a household survey program established with the financial help and sustain of the Bill and Melinda Gates Foundation and implemented by the LSMS team. Understanding that existing data in the region suffers from weak investment, institutional and sectorial isolation, and methodological shortcoming, the LSMS-ISA project cooperates with the national statistics offices of eight partner countries in Sub-Saharan Africa to design and implement systems of multi-topic, nationally representative panel household surveys with a strong focus on agriculture.

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, household 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 focal points of the LSMS-ISA assistance to the IHS program are (i) expansion of the agricultural content of the multi-topic IHS, and (ii) generation of high-quality panel data to adequately portray welfare dynamics.

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 also 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 national-level. The final sample is obtained by merging the LSMSA-ISA survey with soil and nutrients nutrients loss survey.

The SAPP was implemented by the Government of Malawi with the support of IFAD and FAO. The main aim is gathering data to contribute to poverty reduction and improved food security through promotion of GAPs. The survey was piloted in 6 district: Chitipa, Nkhotakota, Lilongwe, Balaka, Chiradzulu and Blantyre, while other 5 districts (Rumphi, Nkhata Bay, Dedza, Ntcheu and Zomba) functioned as a control. In total 1,800 households representative at district level were interviewed. Both the LSMA-ISA and SAPP are useful to obtain information on: soil conditions (plot erosion, causes of erosion problems, plot quality, type of soil, slope, greenness, wetness index, nutrient availability, nutrient retention capacity, toxicity) and soil management (anti-erosion measures, type of irrigation, rate of inputs utilized, crop pattern, diversification index, type of seeds, plantation of trees, fallow period, participation to agricultural programs).

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 centered 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 temperatures accumulations over Africa with Historical rainfall data from 1983-2014 on 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 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 to soil loss, the assessment provides precious information on nutrients loss (phosphorous, potassium, nitrogen and carbon). Both measures are expressed in tons per hectare in 2011 and 2013.

All the data sources here described are merged at EA, household and plot area level so as to allow for a complete cross-sectional dataset rich of economic, social, agronomic and climatic detailed information, and for an in-depth micro and country-representative analysis. Complete descriptive statistics for selected variables at household level are presented in Table 2, while Table 3 presents statistics for variables at plot level.

Table 2: descriptive statistics (household 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	0.42	0.49	0.00	1
flaborshare	Percentage of female labor in the HH (%)	0.47	0.29	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		

Table 3: 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	Potassium loss per ha (grams/ha)	39.58	44.47	0.65	319.65
n	Nitrogen loss per ha (grams/ha)	3855.35	6990.15	15.00	47845.62
c	Carbon loss per ha (grams/ha)	1039.87	837.13	3.42	4179.10

k	Phosphorous 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)	27.85	34.21	0.00	300.00
fert2	Urea (Kg)	21.89	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 4 reports the percentage of adoption of three agricultural practices that we will use to assess their impact in mitigating the nutrient and the soil loss.

Table 4: descriptive statistics (plot level)

Variable	Description	%
D_S_HH	Dummy Shannon index	
0	monocrop plot	55.24
1	diversified plot	44.76
Antierosion	Antierosion measures	
No erosion		62.02
Terraces		3.38
bunds		29.04
Vetiver grass		5.1
Tree belts		0.47
D_fallow	fallow	
0	no fallow in the last three years	86.23
1	fallow in the last three years	13.77

4 Results of economic assessment

4.1 Maize production and soil loss

Table 4 shows the impact of soil loss on maize yield for deciles of the total production distribution. Estimations are obtained at plot level and clustered at household level with both outcome and independent variables expressed in logarithms. The reduction impact of soil loss on maize production range 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 as proxied by education, etc.), whose coefficient signs and magnitudes are in line with the agro-economical literature, we assess the impact of soil loss by controlling also 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 including dummies of the agro-ecological zones interacted with the soil loss variable (not showed in Table 5). We include a covariate for the gender of the household member that controls the management of the plot. We also interact the gender dummy with the soil loss to detect marginal effects of soil loss on productivity when the land is managed by females. Plots managed by females appear less productive, although the gender dummy is significant only in the third and fourth deciles, and the effect is consistent also when interacting the gender dummy with the soil loss measure.

Table 5: 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	-0.613	-0.619	-0.863**	-0.824***	-0.374	-0.156	-0.093	-0.290	0.005
	(0.926)	(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)
groundnut	-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:femhead	0.051	0.055	0.078**	0.074**	0.031	0.006	-0.002	0.018	-0.018
	(0.097)	(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 AEZs, interactions of AEZs with the soil loss measure and year 2013.

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. Despite for tropic-cool/subhumid AEZs these effects are not significant, the impact on the other AEZs are negative and significant, with stronger effects on semiarid AEZs.

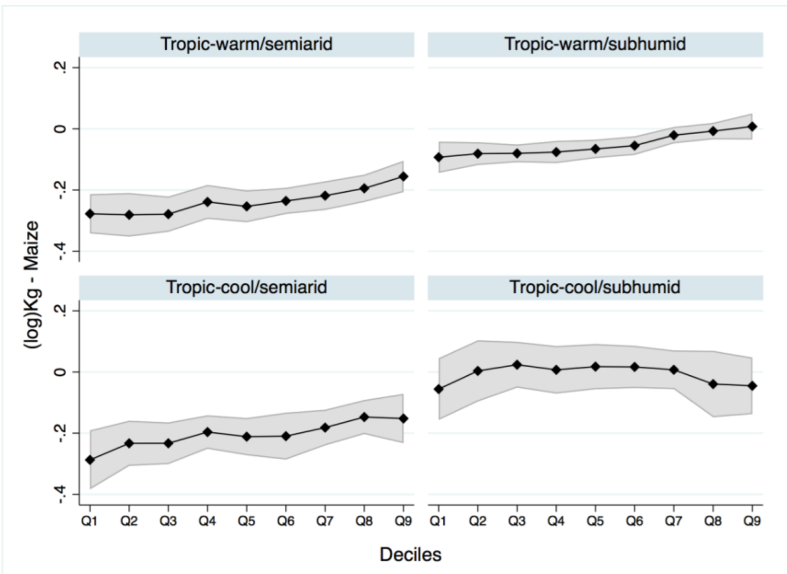

Figure 1: Conditional MEs of soil loss on maize production, with 90% C.I.

Table 6 reports the effect of soil loss on the annual total HH consumption expressed in constant 2010 MWK. Estimates are obtained at 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 households' expenditure. As a control, we also include two agronomic variables which can influence the self-production of food by limiting the needs for food expenditure (the main proportion in total consumption), but, otherwise, can improve their agricultural income thereby allowing for greater consumption. These two drivers are the total area cultivated which affects the total agricultural production and a dummy equal to 1 if the household receives more than 75% of his income from agriculture. Moreover, we control for the level of technology endowment (count of total technological assets such as radio, TV, mobile phones), for access to major infrastructures, and for presence of any parliament member in the community.

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 by the 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 range from -0.025 to -0.032 percent. On the contrary, higher quantiles are not significantly affected by soil loss, given that wealthier households can rely on other sources of income other than agriculture. Interesting, while the femhead coefficient is positive, the share of female labor is negative and significant. If the female heads the HH and decides the level of consumption, this is likely to be higher than consumption of a male headed HH, while a higher share of female labor impact negatively most likely because of lower wages (or productivity) and thus lower consumption. The access to infrastructures, proxied by the distance to major infrastructures, represents a fundamental driver for higher consumption level.

Table 6: Effects of soil loss on HH (log) total real consumption (MWK)

	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	-0.000	-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)
flaborshare	-0.149***	-0.097**	-0.090***	-0.107***	-0.131***	-0.086**	-0.084**	-0.045	-0.003
	(0.054)	(0.041)	(0.027)	(0.030)	(0.040)	(0.037)	(0.041)	(0.046)	(0.048)
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	**-0.025****	**-0.032***	**-0.027***	**-0.025***	**-0.026***	**-0.016**	**-0.005**	**0.002**	**0.006**
	(0.012)	(0.018)	(0.015)	(0.015)	(0.016)	(0.015)	(0.015)	(0.016)	(0.019)
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)
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.

4.2 Maize production and nutrients loss

The majority of soil types in Malawi are generally loamy sand that is moderately acidic (Snapp, 1998). Long-term use of fertilizer (and especially acidic ones) can significantly affect the pH status of the soils and eventually impact on the production of the 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). Urea and 23:21:0+4S are commonly applied to maize, whereas CAN and D compound suit tobacco production. 23:21:0+4S 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. In specific locations in Malawi, certain soil types are low in Zn, which can be identified through distinctive white striping in maize leaves and a maize yield response to compound fertilizers that contain Zn. The new formulation 23:10:5+1Zn, 6S is one such source of Zn that is appropriate for such locations, especially if P deficiency is not an issue.

The effects of nutrients loss on maize production is presented in Table 7 in which we consider the nutrients loss both separately and with interactions terms among the four loss measures to account for interaction effects among nutrients. We find a negative and significant effect of nitrogen loss on maize production, with slightly stronger effects on lower deciles. The impact is in line with the one of total soil loss, and ranges from -0.15 to -0.34 percent. We do not find significant effects due to loss of other nutrients with the exception of the a negative and positive impacts on the first decile of the potassium and carbon loss, respectively. Some positive effect can be detected also for the phosphorous loss. This results seem to suggest both the importance of the nitrogen for maize production and a likely unbalance (excess) of other nutrients. Among the interaction terms, while a contemporaneous loss of potassium and nitrogen has a positive effect on maize production, the contemporaneous loss of potassium and carbon shows a negative impact.

The input and control variables included in the production function are fully consistent with the results obtained in previous agronomic and economic studies.

Table 7: Effect of nutrients 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	0.000	-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)
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)
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)
beans	**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 household level are in parentheses, $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$. Estimates include dummies for AEZs, interactions of AEZs with the nutrient loss measures and year 2013.

4.3 Effect of agricultural practices on soil and nutrient loss

Table 8 reports the treatment effects for adopting two major agricultural practices for which we have sufficient information in the data. The considered practices are crop diversification and anti-erosion measures. The former is represented by a dummy variable based on values of the Shannon index greater than one.

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 Section 3.2, 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 8 represents ATEs and are expressed in kg of soil loss per hectare. Therefore, negative values have to be interpreted as positive effects for HHs, that is as a reduction in soil loss. Table A1 and A2 in the Appendix present 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 two selected practices is estimated.

Adopting diversification measures leads to an average reduction of soil loss of about 6.5 kg/ha, relative to the non-adopting HHs that do not obtain any reduction in soil loss (-1.091 kg/ha). Adopting anti-erosion measures also allows HHs to obtain a reduction in soil loss, although the effect is relatively smaller (5.4 kg/ha) when compared to diversification strategies. However, in the case of anti-erosion the counterfactual effect for non-adopters indicates a larger soil loss reduction (about -6.4 kg/ha) relative to adopter HHs.

In summary, to the extent of our data represent the actual portfolio of agricultural practices available for surveyed Malawian HHs, it is possible to conclude that diversification measures represent effective interventions of a magnitude similar to standard anti-erosion measures. A possible explanation of this evidence is that the proportion of HHs that adopt crop diversification strategies is much larger than the one that rely on mere anti-erosion measures. Therefore, these numbers may reflect this limitation and should be interpreted with caution.

Nevertheless, according to Snapp et al. (2014), a factor that consistently influences maize yield response to nitrogen is rotation with other crops and particularly a legume crop. Legume residues are N-enriched, containing 3 to 5 percent N compared to 1 to 2 percent 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 that have a longer-duration growing period and produce copious amounts of vegetative matter over 6 to 10 months are much more likely to fix appreciable amounts of N, compared to food legumes such as common bean and soybean with a shorter 3 to 4 month growing period.

Table 8: Treatment effects of agricultural practices on soil loss

	Diversification	Anti-erosion
ATE (reduction in kg/ha of soil loss for adopters w.r.t counterfactual)	-6.520	-5.479
	(0.25)	(0.194)
ATT (reduction in kg/ha of soil loss for non adopters if they were adopters)	-1.091	-6.546
	(0.165)	(0.173)

Standard deviations in parentheses.

Table 9 presents the impact of a set of agricultural practices on the nutrient loss relying on the SUR empirical methodology above explained. We report only the coefficients of interest.

Table 9: Effect of practices on soil nutrients (SUR model)

	(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)
antierosion_terraces	-0.048	-0.069	-0.026	0.114
	(0.058)	(0.045)	(0.043)	(0.077)
antierosion_bunds	0.200	0.165	-0.088	0.337*
	(0.152)	(0.117)	(0.113)	(0.203)
antierosion_vetiver_grass	-0.077	-0.132***	-0.173***	-0.227***
	(0.049)	(0.038)	(0.036)	(0.065)

antierosion_tree_belts	-0.073***	-0.088***	-0.034*	-0.199***
	(0.024)	(0.018)	(0.018)	(0.031)
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. Statistica significance: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Estimates include a control for a year dummy (2013).

Five set 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 fertilizers and pesticides utilized increases. Moreover, interaction terms among more adopted fertilizers are included to capture complementarities. Second, crop diversification measures. Third, the adoption of legumes as supporting crop to maize on the same plot. Fourth, a detailed multinomial variable of anti-erosion measures and, fifth, the application of fallow to the plot.

Three main results are found from this model. First, while the use of Chitowe and Urea (fert1 and 2) contributes to reduce all the nutrients loss with the exception of nitrogen, the compound (fert3) fertilizer is the only one that seems to guarantee a support in reducing the loss of nitrogen, while creating an unbalance on the other nutrients. Nevertheless, by combining Chitowe and Urea or Urea and Compound, we obtain a complementarity that contributes to the reduction in all the nutrient loss. The efficient use of Urea requires careful timing of its application to coincide with sufficient moisture in the soil.

Second, the crop diversification reduces the loss of p and n, as well as the adoption of legumes. Third, when disentangling the anti-erosion measures we see that none of these are effective in contrasting the nutrient loss. With respect to not adopting antierosion measures, the application of vetiver grass and a tree belt show the higher impact on reducing the loss and are thus suggested as more effective practices.

The last result is relative to the impact of fallow that seems to produce a significant increase in the loss of p and n, but the results could be biased by the threshold of the time span (three years) over which the fallow should have been adopted. Hence, this evidence should also be interpreted with caution.

4.4 National impacts of soil loss on productivity

To conclude our analysis, we provide a national impact of the soil loss expressed in terms of the total agricultural production value and the GDP. In so doing, we highlight two main shortcomings. First, this impact is not based on a general equilibrium analysis and so it does keep into account potential market and demand adjustments arising between the agricultural and other sectors that are likely to arise when the first becomes less productive because of the soil loss. Second, this impact is based just keeping into account the reduction of maize productivity consequent to the soil loss and not the impact on area where other crops different from maize are cultivated. As a consequence of these two limitations, the national impact must be intended as a lower bound in a partial equilibrium analysis.

To estimate the impact of soil loss at national level we use the average elasticity obtained from Table 4, by multiplying this latter for the national total production value of maize according to the FAOSTAT data, so as to obtain the average reduction of maize production value deriving from a one per cent increase in the soil loss. The ratio between the delta production value and the total agricultural production value, or between the delta production value and the GDP, allow us to see the magnitude of the monetary losses caused by the soil loss in terms of other macroeconomic variables.

All the macroeconomic data are reported in the Table 10, which shows as the impact of a one per cent increase in soil loss is associated to a monetary loss at national level that corresponds to the 2.5 per cent of GDP, or the 4 per cent on the agricultural production value.

Table 10: Macroecomic variables and national impact of 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	%	2.562%
F	Impact of soil loss in terms of agricultural production value = (D*C)/B	%	4%

Substantial variability exists in the literature on the estimates of economic impacts of soil loss. To compare, 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 cost of 1.6% of total GDP in 2007. Given the different methodology used our estimates are not directly comparable but nevertheless fall within the range of values found in the literature.

5 Conclusions

The study confirms the negative impact of soil loss on maize production with an average of -0.23%. Taking into account the erosion rate and the total value of maize production, economic loss is estimated to be around 2.5% of GDP. Substantial variability exists in the literature on the estimates of economic impacts of soil loss in Malawi but nevertheless our estimates fall within the range of values found in the literature.

The impact of soil loss on the total household consumption is concentrated along the lower consumption deciles as poorer farmers have lower access to other income sources and are thus strictly dependent by the agricultural and agro-ecological conditions. Employing the SPEI to control for drought and rainfall shocks yields the same results with negative impact of per capita consumption level only for lower deciles.

We find a negative and significant effect of nitrogen loss on maize production, with slightly stronger effects on lower deciles. The impact is in line with the one of total soil loss, and ranges from -0.15 to -0.34 percent. There are no significant effects due to loss of other nutrients confirming the importance of the nitrogen for maize production.

The results of this study suggest that soil erosion is not a threat to food security in Malawi.

Soil conservation measures are found to mitigate the economic impact of soil loss. In particular, both crop diversification and anti-erosion measures represent effective interventions with similar magnitude. Crop diversification also reduces the loss of p and n, as well as does the adoption of legumes. The application of vetiver grass and a tree belt show the higher impact on reducing the loss of nutrients and are thus suggested as more effective practices. Among fertilizer types, the use of Chitowe and Urea contributes to reduce all the nutrients loss with the exception of nitrogen, the compound-D fertilizer is the only one that seems to guarantee a support in reducing the loss of nitrogen, while creates an unbalance on the other nutrients. Nevertheless, combining Chitowe and Urea or Urea and Compound we obtain a complementarity that contributes to the reduction in all the nutrient loss.

Appendix

Table A1: Effect of crop diversification on soil loss – 2011 and 2013

	Dep. variable: soil loss		
	Adopters	Non-adopters	Select (S_HH=1)
agehead	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)
femhead	0.060*	0.022	0.074**
	(0.032)	(0.025)	(0.030)
educave	-0.033***	-0.002	-0.029***
	(0.006)	(0.005)	(0.005)
hhsize	-0.020***	0.002	-0.021***
	(0.006)	(0.005)	(0.006)
disturban	-0.022**	-0.052***	-0.049***
	(0.009)	(0.010)	(0.009)
wealth	-0.008	-0.001	-0.020
	(0.012)	(0.012)	(0.012)
infraindex	0.024	-0.000	-0.005
	(0.017)	(0.015)	(0.016)
owner	0.746	1.406***	-2.002***
	(0.602)	(0.162)	(0.514)
plot_area	-0.093***	0.003	-0.082***
	(0.019)	(0.015)	(0.017)
MV	-0.210***	0.001	-0.231***
	(0.027)	(0.023)	(0.025)
s_r_spei	-0.305***	-0.037	-0.396***
	(0.035)	(0.029)	(0.032)
s_d_spei	0.558***	0.169***	0.363***
	(0.034)	(0.028)	(0.031)
tech_endow			0.036**
			(0.015)
Constant	9.506***	8.371***	2.361***
	(0.609)	(0.177)	(0.520)
lnsigma	0.105***	-0.400***	
	(0.012)	(0.012)	
rho	2.718***	0.105	
	(0.073)	(0.080)	
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.

Table A2: Effect of anti-erosion practices on soil loss - 2011 and 2013

	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.

6 References

Abdulai, A., & Huffman, W. E. (2005). The diffusion of new agricultural technologies: The case of crossbred-cow technology in Tanzania. *American Journal of Agricultural Economics*, *87*(3), 645-659.

Abrevaya J., Dahl C. M., (2001). The effects of demographics and maternal behavior on the distribution of birth outcomes. Empirical Economics, vol. 26(1), pp. 247-257.

Abrevaya J., Dahl C. M., (2008). The effects of birth inputs on birthweight: evidence from quantile estimation on panel data. Journal of Business and Economic Statistics, vol. 26(4), pp. 379-397.

Alene, A., Manyong, V.M., (2007). The effect of education on agricultural productivity under traditional and improved technology in northern Nigeria: an endogenous switching regression analysis. *Empirical Economics* 32, 141–159

Amphlett, M.B., (1986). Soil Erosion Research Project, Bvumbwe, Malawi, Summary Report, Hydraulics Research, Wallingford.

Amphlett, MB. (1984). Measurement of soil loss from experimental basins in Malawi. Challenges in African Hydrology and Water Resources (Proceedings of the Harare Symposium, July 1984). IAHS Publ. no. 144 .

Asfaw,S., Pallante G., Palma A. (2018). Diversification Strategies and Adaptation Deficit: Evidence from Rural Communities in Niger. World Development, vol. 101, pp. 219-234.

Asfaw, S. McCarthy, N., Lipper, L., Arslan, A., Cattaneo, A., & Kachulu, M., (2014). Climate variability, adaptation strategies and food security in Malawi (ESA Working Paper No. 14-08). Rome: FAO.

Avwunudiogba, A.; Hudson, P.F., (2014). A Review of Soil Erosion Models with Special Reference to the needs of Humid Tropical Mountainous Environments. Eur. J. Sustain., 3, 299–310.

Benin S., Thurlow J., Xinshen D., McCool C. and F Simtowe (2008), Agricultural Growth and Investment Options for Poverty Reduction in Malawi, IFPRI Discussion Paper 00794.

Bennett H.H. (1933). The cost of soil erosion. The Ohio Journal of Science 33: 271-279.

Bishop, J., (1995). The Economics of Soil Degradation: An Illustration of the Change in Productivity Approach to Valuation in Mali and Malawi, London: International Institute for Environment and Development.

Boserup, E., (1965). The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure. Allen & Unwin, London.

Canay I. A., (2011). A simple approach to quantile regression for panel data. The Econometrics Journal, vol. 14(3), pp. 368-386.

Cavatassi, R., Lipper, L., & Narloch, U. (2011). Modern variety adoption and risk management in drought prone areas: insights from the sorghum farmers of eastern Ethiopia. *Agricultural Economics*, 42(3), 279-292.

Dougill, A. J., Whitfield, S., Stringer, L. C., Vincent, K., Wood, B. T., Chinseu, E. L., Steward, P., & Mkwambisi, D. D., (2017). Mainstreaming conservation agriculture in Malawi: Knowledge gaps and institutional barriers. Journal of Environmental Management, 195(1), 25-34.

Chernozhukov V., Fernández-Val I., (2011). Inference for Extremal Conditional Quantile Models, with an Application to Market and Birthweight Risks. The Review of Economic Studies, vol. 78(2), pp. 559-589.

D'Odorico, P., Bhattachan, A., Davis, K. F., Ravi, S., & Runyan, C. W. (2013). Global desertification: Drivers and feedbacks. Advances in Water Resources, 51, 326–344.

Di Falco, S., Veronesi, M., & Yesuf, M. (2011). Does adaptation to climate change provide food security? A micro-perspective from Ethiopia. American Journal of Agricultural Economics, 93(3), 829-846.

Eswaran, H., Lal, R. & Reich, P. F., (2001). Land Degradation: an Overview. Proceedings of the 2nd International Conference on Land Degradation and Desertification, Khon Kaen, Thailand: Oxford Press.

Gassman, P.W., Reyes M. R., Green C. H., Arnold J. G., (2007). The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. Transactions of the ASABE. Vol. 50(4): 1211-1250.

Giertz A., Caballero J., Dileva M., Galperin D., Jackson T., (2015). Managing Agricultural Risk for Growth and Food Security in Malawi. Agriculture Global Practice Note. 100124. World Bank Group.

GoM (undated). The national fertilizer strategy for Malawi. Ministry of Agriculture, Lilongwe. http://fsg.afre.msu.edu/mgt/caadp/format_for_national_fertilizer_strategy9.pdf

Greene W. (2008). Econometric Analysis (6th Ed.) Prentice Hall, Englewood Cliffs, NJ.

Jones, A., Breuning-Madsen, H., Brossard, M., Dampha, A., Deckers, J., Dewitte, O., Gallali, T., Hallett, S., Jones, R., Kilasara, M., Le Roux, P., Micheli, E., Montanarella, L., Spaargaren, O., Thiombiano, L., Van Ranst, E., Yemefack, M. , Zougmoré R., (eds.), 2013. Soil Atlas of Africa. European Commission, Publications Office of the European Union, Luxembourg. 176 pp.

Hirschi, M. C., Barfield B. J., (1988). KYEMO- A physically based research erosion model. Part I: Model development Transactions of the American Society of Agricultural Engineers 31, 804-813.

Ito, M., Natsumoto, T., Quinones, M.A., (2007). Conservation tillage practice in Sub-Saharan Africa: the experience of Sasakawa Global 2000. Crop Prot. 26, 417e423.

Kaluzi, L., Thierfelder C., Hopkins, D. W., (2017). Smallholder Farmer Innovation and Contexts in Maize-Based Conservation Agriculture Systems in Central Malawi. Sustainable Agriculture Research, [S.l.], v. 6, n. 3, p. p85, june 2017. ISSN 1927-0518. Available at: <http://www.ccsenet.org/journal/index.php/sar/article/view/67375>. Date accessed: 01 aug. 2017. doi:http://dx.doi.org/10.5539/sar.v6n3p85.

Knisel, W. G. (1980). CREAMS: A field Scale model for Chemicals, Runoff and Erosion From Agricultural management Systems. In Conservation Research Report Washington: US Department of Agriculture

Knisel, W. G., Turtola E., (2000). GLEAMS model application on a heavy clay soil in Finland. Agricultural Water Management, 43, 285-309.

Koenker R., Hallock K. F., (2001). Quantile Regression. Journal of Economic Perspectives, Vol. 15(4), pp- 143-156.

Lal, R. (1995). Erosion-crop productivity relationships for soils of Africa. Soil Science Society of America Journal, 59(3), 661–667.

Lambin, E.F.; Geist, H, (2006). Land-Use and Land-Cover Change Local Processes and Global Impacts. Springer.

Leonard, R. A., Knisel W. G., Davis F. M., (1995). Modelling pesticide fate with GLEAMS. European Journal of Agronomy, 4, 485-490.

Ligowe, I., Ngwira, A.R., Kamalongo, D., (2013). DARS Extension Circular: Conservation Agriculture (CA) - a Way to Sustainable Agriculture. Ministry of Agriculture and Food Security, Lilongwe.

Lokshin, M., & Sajaia, Z. (2004). Maximum likelihood estimation of endogenous switching regression models. *Stata Journal*, 4, 282-289.

Lovo S., (2016). Tenure Insecurity and Investment in Soil Conservation. Evidence from Malawi. World Development, Volume 78, 2016, Pages 219-229.

Maddala, G. S. (1983). *Limited-dependent and qualitative variables in econometrics* (No. 3). Cambridge University Press.

Maddala, G.S., Nelson, F.D., (1975). Switching regression models with exogenous and endogenous switching. In: *Proceeding of the American Statistical Association* (Business and Economics Section), pp. 423–426.

Marenya, P., Smith, V.H., Nkonya, E., (2014). Relative Preferences for Soil Conservation Incentives among Smallholder Farmers: Evidence from Malawi. Am. J. Agric. Econ. 1– 21. doi:10.1093/ajae/aat117

MEMP (1996), Soil Erosion Project 1981/92.

Mlava J., A. Mtethiwa, W. Mgoola, and S. Makungwa, (2010). Case studies prepared for MPEI Economic Study, Lilongwe.

Mutegi J., Kabambe V., Zingore M., Harawa R., Waiegi L. (2015). The Status of Fertilizer Recommendation in Malawi: Gaps, Challenges and Opportunities. CABI, Nairobi.

Nakhumwa, T.O., (2004). Dynamic Cost of Soil Degradation and Determination of Adaptation of Soil Conservation Technology by Smallholder Farmers in Malawi, unpublished PhD. Dissertation, University of Pretoria, Pretoria.

Nguyen, T. T., Nguyen, L. D., Lippe, R. S., & Grote, U. (2017). Determinants of farmers' land use decision-making: Comparative evidence from Thailand and Vietnam. World Development, vol. 89, pp. 199–213.

Ngwira, A. R., Thierfelder, C., Lambert, D. M., (2012). Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. Renew. Agr. Food Syst. 28, 350–363.

Ngwira, A.R., Aune, J.B., Mkwinda, S., (2012b). On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. Field Crops Research 132, 149–157.

Nkonya E., Mirzabaev A., von Braun J. (eds.), (2016). Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development. Springer, New York.

Noltze, M., Schwarze, S., & Qaim, M. (2013). Impacts of natural resource management technologies on agricultural yield and household income: The system of rice intensification in Timor Leste. *Ecological Economics*, *85*, 59-68.

Oldeman, L., Hakkeling, R. & Sombroek, W., 1991. World Map of the Status of Human-Induced Soil Degradation: An Explanatory Note (Global Assessment of Soil Degradation (GLASOD)), Wageningen and Nairobi: International Soil Reference and Information Centre and United Nations Environment Programme.

Ortega D. L., Waldman K. B., Richardson R. B., Clay C. D., Snapp S., (2016). Sustainable Intensification and Farmer Preferences for Crop System Attributes: Evidence from Malawi's Central and Southern Regions, World Development, Volume 87, 2016, Pages 139-151.

Panagos, P., Standardi, G., Borrelli, P., Lugato, E., Montanarella, L., & Bosello, F., (2018). Cost of agricultural productivity loss due to soil erosion in the European Union: From direct cost evaluation approaches to the use of macroeconomic models. Land Degradation & Development, 29(3), 471-484.

Panagos P., Borrelli P., Meusburger K., Alewell C., Lugato E., Montanarella L., (2015). Estimating the soil erosion cover-management factor at the European scale. Land Use Policy, 48, pp. 38-50.

Pittelkow C. M., Liang X., Linquist B.A., Van Groenigen K.J., Lee J., Lundy M.E., Van Gestel N., Six J., Venterea R.T., van Kessel C., 2015. Productivity limits and potentials of the principles of conservation agriculture. Nature, 517, pp. 365-368.

Phiri, M. A. R., Chilonda, P., & Manyamba, C., 2012. Challenges and opportunities for raising agricultural productivity in Malawi. Int. J. Agric. 2, 210-224. http://dx.doi.org/10.5923/j.ijaf.20120205.04

Renard, K. G., Foster G. R., Weesies G.A., Porter J.P., 1991. RUSLE - Revised Universal Soil Loss Equation. Journal of Soil and Water Conservation, 46, 30-33.

Ricker-Gilbert J., Jumbe C., Chamberlin J., 2014. How does population density influence agricultural intensification and productivity? Evidence from Malawi. Food Policy 48: 114-128

Snapp, S., Jayne, T. S., Mhango, W., Benson, T., & Ricker-Gilbert, J., (2014). Maize yield response to nitrogen in Malawi's smallholder production systems. Malawi Strategy Support Program, Working Paper, 9.

Snapp, S.S., (1998). Soil nutrient status of smallholder farms in Malawi, Communications in Soil Science and Plant Analysis, 29:17-18, 2571-2588, DOI: 10.1080/00103629809370135

Telles T.S., Guimarães M.F., Dechen S.C.F., (2011). The costs of soil erosion. Revista Brasileira de Ciência do Solo 35: 287-298.

Thierfelder, C., Matemba-Mutasa, R., Bunderson, W. T., Mutenje, M., Nyagumbo, I., & Mupangwa, W., (2016). Evaluating manual conservation agriculture systems in southern Africa. Agriculture Ecosystems and Environment, 222,112-124. http://doi.org/10.1016/j.agee.2016.02.009

Thierfelder, C., Bunderson, W. T., Zwide, J., Mutenje, M., & Ngwira, A., (2015). Development of conservation agriculture systems in Malawi: lessons learned from 2005-2014. Experimental Agriculture, 52(4), 579-604.

Thierfelder, C., Chisui, J. L., Gama, M., Cheesman, S., Jere, Z. D., Bunderson, W. T., Eash, N. S., Ngwira, A. R., & Rusinamhodzi, L., (2013). Maize-based conservation agriculture systems in Malawi: Long-term trends in productivity. Field Crops Research, 142, 47-57. http://dx.doi.org/10.1016/j.fcr.2012.11.010

UNCCD, (2012). Desertification: A Visual Synthesis, s.l.: United Nations Convention to Combat Desertification (UNCCD).

UNEP, (2015). The Economics of Land Degradation in Africa. ELD Initiative, Bonn, Germany. Available from www.eldinitiative.org.

Vargas R., Omuto CT. (2016). National topsoil loss assessment in Malawi. FAO, Rome (http://www.fao.org/documents/card/en/c/58120aec-a49b-4f84-ad31-f9d920c1f7fa/)

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., & Six, J. (2011). Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility management. Plant and soil, 339(1-2), 35-50.

Wale, H. A., & Dejenie, T., (2013). Dryland ecosystems: Their features, constraints, potentials and managements. Research Journal

Waddington, S.R., Zingore, S., Chikowo, R., Wairegi, L. and Snapp, S., (2015). Integrated Fertilizer Policy Guide for Maize – Legume Cropping Systems in Malawi. Ibadan, Nigeria: IITA.of Agricultural and Environmental Management, 2(10), 277–288.

Ward, P.S., Bell, A.R., Parkhurst, G.M., Droppelmann, K., Mapemba, L., (2016). Heterogeneous Preferences and the Effects of Incentives in Promoting Conservation Agriculture in Malawi. Agriculture, Ecosystems and Environment 222 (2016) 67–79.

Williams, J. R., Renard K.G., Dyke P. T., (1983). Epic - a New Method for Assessing Erosions Effect on Soil Productivity. Journal of Soil and Water Conservation, 38, 381-383.

Wischmeier W. H., Smith D. D., (1978). Predicting rainfall erosion losses: A guide to Conservation Planning.Washington DC: US Department of Agriculture Hand Book 537 US Government Printer Office.

World Bank. 2017. World Development Indicators, (2017). Washington, DC. World Bank.

World Bank, (1992). Malawi Economic Report on Environmental Policy. World Bank, Lilongwe, Malawi.

Yaron, G., R. Mangani, J. Mlava, P. Kambewa, S. Makungwa, A. Mtethiwa, S. Munthali, W. Mgoola and J. Kazembe, (2011). Economic Valuation of Sustainable Natural Resource Use in Malawi. Ministry of Finance and Development Planning, Malawi Government.