A synergy between the biophysical and the economic: the global market impacts of soil erosion

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Abstract

Employing a linkage between a biophysical and an economic model, this study estimates the economic impact of soil erosion by water on the world economy. The global biophysical model estimates soil erosion rates, which are converted into land productivity losses and subsequently inserted into a global market simulation model. The headline result is that soil erosion by water is estimated to incur a global annual cost of eight billion US dollars to global GDP. The concomitant impact on food security is to reduce global agri-food production by 33.7 million tonnes with accompanying rises in agri-food world prices of 0.4 % to 3.5 %, depending on the food product category. Under pressure to use more marginal land, abstracted water volumes are driven upwards by an estimated 48 billion cubic meters. Finally, there is tentative evidence that soil erosion is accelerating the competitive shifts in comparative advantage on world agri-food markets.

Keywords: soil erosion, land productivity loss, computable general equilibrium, model integration, global economy, agriculture

Introduction, scope and main objectives

Employing a linkage between a biophysical and an economic model, this study estimates the economic impact of soil erosion by water on the world economy.

In a changing world of eight billion people with the critical threats of climate change, water scarcity and depletion of soil fertility, the agricultural economy should adapt taking into account environmental and ecological aspects (Altieri and Nicholls, 2017). A key element for ensuring a sustainable system of food production is linked to effective soil management, which implies a reduction of soil erosion rates (Poesen, 2018). Among various land degradation processes, soil erosion is recognized as a major environmental problem causing loss of topsoil and nutrients, reduced soil fertility (Zhao *et al.*, 2013) and, as a consequence, reduces crop yields (Telles *et al.*, 2011). Furthermore, soil erosion may increase the losses of CO2, exacerbating the climate change (Lugato *et al.*, 2018).

A recent estimation of land degradation costs shows that the global economic impact is highly uncertain, from 40 to 490 billion US$, and varies from country to country (Nkonya *et al.*, 2016). More than two decades ago, Pimentel *et al.* (1995) estimated the on-site costs of water erosion in the United States of America to be about 16 billion US$ per year based on expert knowledge. Similarly, the agricultural productivity loss due to soil erosion in the European Union is estimated to be around 300 million € (Panagos *et al.*, 2018) using a combination of the recent soil loss assessment and the well-known Global Trade Analysis Project (GTAP) computational general equilibrium (CGE) simulation model. A recent application on the African continent estimates the annual loss of crop yield to be about 280 million tonnes (Wolka *et al.*, 2018), compared with only six million tonnes estimated in the European Union.

With one notable exception (Panagos *et al.*, 2018), a typical feature of these studies is that they carry out a 'first-order' cost evaluation exercise focusing in agricultural production losses (e.g., Erkossa *et al.*, 2015). More specifically, the economic value of land productivity loss is calculated by the direct loss in production of the affected crops (tonnes) multiplied by their respective average market prices ($/tonnes). This analysis does not, however, capture the resulting 'second-round' effects of economic structural change that arise owing to shifts in primary resources, particularly the land factor.

Methodology

This study estimates the impact of soil erosion by water on the world economy, employing a linkage between a biophysical and an economic model. To the best of our knowledge, there is no study that fully captures the aforementioned structural impacts from land productivity losses due to soil erosion at the global scale. To close this gap in the literature, an approach akin to Panagos *et al.* (2018) is followed. Soil erosion rates are first estimated by the Global RUSLE biophysical model (Borrelli *et al.*, 2017), converted into land productivity losses and then fed into the Modular Applied GeNeral Equilibrium Tool (MAGNET) (Woltjer and Kuiper, 2014). Whilst the core of MAGNET is the GTAP model, it is superior to GTAP because it contains a greatly improved treatment of agricultural factor markets. The counterfactual thus captures the resulting marginal market impacts in agricultural (and non-agricultural) activities, which arise in each region due to soil erosion.

Results

As a headline Figure, the results show that soil erosion is unambiguously detrimental to global food production, resulting in a non-trivial decline in agricultural and food production of 33.7 million tonnes. Due to the lower amount of agri-food products available in the international markets and the consequent price increase, the total value of these goods has increased by 24.9 billion US$. Globally, land demand increases by approximately 223 000 km^2, equivalent to a 0.5 % increase in global land use in agriculture. The largest contributions arise from cereals (27 %), driven by the positive change in production, horticulture (19 %) and oil seeds (19 %) activities. Globally, soil erosion has also brought about a 1.6 % increase of the water withdrawn for agricultural purposes (which is equal to more than 48 billion cubic meters). In absolute terms, China, Indonesia and South-East Asia represent approximately 14 %, 12 % and 23 % of the global increase, due to the irrigation intensive system of rice production. In proportional terms, Brazil, the 'USA and Canada' region and South America witness water abstraction increases of up to 5 %. Detailed results can be found in Sartori *et al.*, 2019.

Discussion

Compared with previous ‘first-order’ estimates of soil erosion costs, these findings draw markedly different conclusions. For example, in contrast to 'first order' estimates from Wolka *et al.* (2018), who measure a soil erosion driven production loss of 280 million tonnes in Africa, our study reveals a surprisingly diverse picture. Crop production in the African continent increases marginally by 0.35 million tonnes (due to the positive production changes in South Africa and North African countries), since marginal land productivity losses for this continent as a whole are estimated to be lower than in other regions (e.g., China, Brazil, Indonesia). Nonetheless, within the Sub-Saharan African region, the prospects for a number of African countries are more concerning. For example, some West African (Cameroon, Cote d'Ivoire, Ghana and Nigeria) and East African countries (Ethiopia, Kenya, Madagascar and Rwanda) suffer losses in horticultural and cereals production, which are typically high value added cash crops for these countries. Drilling down into the results, one also observes that even with an erosion shock corresponding to a single year, there are noticeable global shifts in agricultural production in China, India and Brazil. These changes are particularly prevalent in the production of rice (and oilseeds on a lesser degree), which decreases by almost 0.5% globally. Indeed, our study reveals that falling land productivity, particularly for rice production, is a major driver of increased water abstraction in Asia. From a trade perspective, the heterogeneous rates of erosion across the planet give rise to accelerating current trends where net agri-food exporters such as USA, Canada, Europe and Oceanian countries continue to improve their net trade balances at the cost of net food importers such as China and South East Asian countries.

Conclusions

In the context of the broader debate, this study provides a direct input into recent strategies such as the Economics of Land Degradation initiative (ELD, 2015; Nkonya *et al.*, 2016) and the Global Land Outlook (GLO) currently proposed by United Nations Convention to Combat Desertification (UNCCD).

The economic effects of soil erosion call for the prioritization of soil governance and conservation strategy in all countries and international policy agenda. In this regard, the European Commission launched the Seventh Environment Action Programme, which requires that by 2020 land is managed sustainably and soil is adequately protected (Paleari, 2017). Focusing on agricultural land, the EU's Common Agricultural Policy (CAP) links support directly to the need to maintain agricultural land in good condition, whilst the post- 2020 CAP includes as one of its main objectives, efficient soil management linked to actions to reduce soil erosion and increase soil organic carbon (Panagos and Katsoyiannis, 2019). In the USA, the Farm Bill extends soil conservation compliance requirements in order to qualify for the crop insurance subsidy (Islam *et al.*, 2014). At global scale, the FAO and its Global Soil Partnership launched in June 2018 a new programme to reduce soil degradation for greater food and nutrition security in Africa.

Measures aimed at reinforcing ecosystem services, ad hoc regulation of human interventions and active farmers' participation contribute to minimize soil erosion. To this aim, protection and restoration of diverse plant communities on slopes are essential, as trees and diversified vegetation increase soil resistance to rain erosivity (Berendse *et al.*, 2015). Other measures such as reduced tillage, buffer strips, agroforestry, plant residues and cover crops enhance soil fertility and control water runoff (Triplett and Dick, 2008).

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References

Altieri, M.A. & Nicholls, C.I. 2017. The adaptation and mitigation potential of traditional agriculture in a changing climate. *Climatic Change*, 140(1): 33-45.

Berendse, F., van Ruijven, J., Jongejans, E. & Keesstra, S. 2015. Loss of plants pecies diversity reduces soil erosion resistance. *Ecosystems*, 18: 881-888. DOI:10.1007/s10021-015-9869-6.

Borrelli, P., Robinson, D.A., Fleischer, L.R., Lugato, E., Ballabio, C., Alewell, C., Meusburger, K., Modugno, S., Schütt, B. & Ferro, V. 2017. An assessment of the global impact of 21st century land use change on soil erosion. *Nature communications,* 8.

ELD Initiative. 2015. Report for policy and decision makers: Reaping economic and environmental benefits from sustainable land management. Available from www.eld-initiative.org at the web address: http://www.eld-initiative.org/fileadmin/pdf/ELD-pm-report_05_web_300dpi.pdf.

Erkossa, T., Wudneh, A., Desalegn, B. & Taye, G. 2015. Linking soil erosion to on-site financial cost: lessons from watersheds in the Blue Nile basin. *Solid Earth*, 6(2): 765-774.

Islam, R. & Reeder, R. 2014. No-till and conservation agriculture in the United States: an example from the David Brandt farm, Carroll, Ohio. *International Soil and Water Conservation Research*, 2(1): 97-107.

Lugato, E., Smith, P., Borrelli, P., Panagos, P., Ballabio, C., Orgiazzi, A., Fernandez-Ugalde, O., Montanarella, L. & Jones, A. 2018. Soil erosion is unlikely to drive a future carbon sink in Europe. *Science Advances*, 4 (11), art. no. eaau3523.

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Shpritz, L., Fitton, L. & Saffouri, R. 1995. Environmental and economic costs of soil erosion and conservation benefits. *Science,* 267: 1117–1123. DOI: 10.1126/science.267.5201.1117.

Nkonya, E., Anderson, W., Kato, E., Koo, J., Mirzabaev, A., von Braun, J. & Meyer, S. 2016. Global Cost of Land Degradation. in: Nkonya, E., Mirzabaev, A., von Braun, J. (Eds.), *Economics of Land Degradation and Improvement – A Global Assessment for Sustainable Development.* Springer International Publishing, Cham, pp. 117–165.

Paleari, S. 2017. Is the European Union protecting soil? A critical analysis of Community environmental policy and law. *Land use policy*, 64: 163-173.

Panagos, P. & Katsoyiannis, A. 2019. Soil erosion modelling: The new challenges as the result of policy developments in Europe. *Environmental Research*, 172: 470-474.

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: 471–484.

Poesen, J. 2018. Soil erosion in the Anthropocene: Research needs. *Earth Surface Processes and Landforms,* 43: 64–84.

Sartori, M., Philippidis, G., Ferrari, E., Borrelli, P., Lugato, E., Montanarella, L. & Panagos, P. 2019. A linkage between the biophysical and the economic: Assessing the global market impacts of soil erosion. *Land Use Policy*, 86: 299-312.

Telles, T.S., Guimarães, M.D.F. & Dechen, S.C.F. 2011. The costs of soil erosion. *Revista Brasileira de Ciência do Solo*, 35(2): 287-298.

Triplett, G.B. & Dick Jr, W.A. 2008. No-tillage crop production: a revolution in agriculture! *Agronomy Journal*, 100: S153–S165. DOI:10.2134/agronj2007.0005c.

Wolka, K., Mulder, J. & Biazin, B. 2018. Effects of soil and water conservation techniques on crop yield, runoff and soil loss in Sub-Saharan Africa: A review. *Agricultural Water Management,* 207: 67–79.

Woltjer, G.B. & Kuiper, M.H. 2014. The MAGNET Model: Module description. Wageningen, LEI Wageningen UR (University & Research centre), LEI Report 14-057.

Zhao, G., Mu, X., Wen, Z., Wang, F. & Gao, P. 2013. Soil erosion, conservation, and eco-environment changes in the Loess Plateau of China. *Land Degradation & Development,* 24: 499–510.