

Assessing the effectiveness of Sustainable Land Management for large-scale climate change adaptation

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Abstract

Climate change will strongly affect essential ecosystem services, like the provision of freshwater, food production, soil erosion and flood control. Sustainable Land Management (SLM) practices are increasingly promoted to contribute to climate change adaptation, but there is lack of evidence at scales most relevant for policymaking. We evaluated the effectiveness of SLM in a large Mediterranean catchment where climate change is projected to significantly reduce water security. We show that the on-site and off-site impacts of climate change are almost entirely reversed by the large-scale implementation of SLM under moderate climate change conditions, characterized by limited reductions in annual precipitation but significant increased precipitation intensity. Under more extreme reductions of annual precipitation, SLM implementation reduces the impacts on water security, but cannot prevent significant increased plant water stress and reduced water availability. Under these conditions, additional adaptation measures are required considering their interactions and trade-offs regarding water security and soil erosion.

Keywords: sustainability, rainfed agriculture, soil erosion, extreme events, water security

Introduction, scope and main objectives

In the coming decades, climate change will strongly affect global socio-ecological systems by altering the hydrological cycle, agricultural production potential and essential ecosystem services. For many areas worldwide, climate projections foresee less rainfall and more extreme weather events, causing decreased water availability and food production, and increased soil erosion and flood frequency (Eekhout *et al.*, 2018a). To prevent devastating impacts for human well-being and help prepare society achieve the Sustainable Development Goals, climate change mitigation and adaptation are major priorities for the coming decades. Recent scientific studies and policy initiatives suggest that Sustainable Land Management (SLM) practices can contribute significantly to climate change adaptation and mitigation. SLM refers to a range of technologies, policies and activities aiming for integrated management of soil, water, vegetation, and biodiversity to support long-term productive ecosystems by integrating biophysical, socio-cultural and economic needs and values.

In this research we quantify the on-site and off-site impacts of SLM based climate change adaptation on soil and water resources and related ecosystem services. We applied a coupled hydrology-soil erosion model to a large Mediterranean study area, where climate change is expected to have a significant negative impact on water security in the coming century (Eekhout *et al.*, 2018a). We evaluated the effectiveness of SLM with on-site (hillslope erosion and plant water stress) and off-site (reservoir inflow, flood discharge and reservoir sediment yield) water security indicators. The results aim to increase insight

in the effectiveness of SLM to alleviate the on-site and off-site impacts from drought and extreme weather at regional scales, most relevant for policy makers.

Methodology

This study is performed in the Segura River catchment in the southeast of Spain, covering an area of 15,978 km². Catchment-averaged annual rainfall amounts to 361 mm (1981-2000). The climate is Mediterranean in the headwaters (19 %) and semi-arid in the rest of the catchment (81 %). The dominant landuse types are shrubland (28 %), forest (26 %), cereals (14 %) and almond orchards (9 %). Agriculture covers 44 % of the catchment. There are 33 reservoirs in the catchment (total capacity 1230 Hm³) for irrigation, electricity supply and flood prevention.

We applied the SPHY-MMF model (Eekhout *et al.*, 2018), a spatially distributed hydrological model, fully coupled with a soil erosion model, and runs with a daily time step. The model simulates the most relevant hydrological (e.g. interception, evapotranspiration, surface runoff) and soil erosion processes (e.g. soil detachment by raindrop impact and runoff, sediment routing, sediment deposition) and incorporates a dynamic vegetation model.

We identified realistic SLM practices for the study catchment based on a review of previous local stakeholder consultation processes and scientific literature reporting on the impacts of SLM practices obtained from field experiments (Almagro *et al.*, 2016). Low-cost practices were identified as most promising and feasible SLM options providing benefits for soil quality, erosion reduction and soil water retention. We applied two types of SLM, i.e. reduced tillage (RT) for cereals, and reduced tillage in combination with green manure (RT+GM) for tree crops and vineyards, which account for 38% of the total catchment area. Green manure is a SLM technique where a mixture of cereals and leguminous cover crops (*Vicia sativa*) are seeded in autumn and ploughed into the soil in early spring.

We applied four different future climate scenarios, divided over two future periods and two Representative Concentration Pathways (RCPs). We have indicated the scenarios as follows: S1 (RCP4.5, 2031-2050), S2 (RCP4.5, 2081-2100), S3 (RCP4.5, 2031-2050) and S4 (RCP4.5, 2081-2100). We compare results for these future scenarios with a reference scenario (1981-2000).

Results

Impact of Climate Change

Climate change leads to a significant increase of plant water stress throughout the catchment. In scenarios S1-3 a moderate average on-site increase of plant water stress is projected of around 5.3-5.9%, while for S4 a more severe increase of 13.4 % is projected (Table 1). In scenarios S1-3 catchment total reservoir inflow (24-29 %) and catchment-average flood discharge (25.2-29.8 %) increase significantly. However, in scenario S4 a significant 25.0-60.3 % decrease of flood discharge is projected in 6 headwater subcatchments. Hillslope erosion is projected to increase for all scenarios between 33.7 % to 55.0 % in almost the entire catchment. Reservoir sediment yield also increases in scenarios S1-S3, but significant changes are only observed in S4 with a decrease of 29.2 %.

Adaptation with SLM

Large-scale implementation of SLM mitigates the increased plant water stress under climate change in scenarios S1-3, for which only a small but non-significant catchment-average increase of 0.8-1.6 % is

projected. However, also after implementation of SLM, plant water stress still significantly increases with 9.5% in scenario S4. Catchment total reservoir inflow still increases in scenarios S1-3 with 8-11 %, while in scenario S4 a decrease of reservoir inflow of 9 % is projected. Similar results are obtained for flood discharge. With SLM, hillslope erosion is projected to decrease with 5.3-18.8 %. A decreased catchment total reservoir sediment yield is projected for all future climate scenarios (S1-4), with significant changes for scenario S4 (-41.4 %).

Table 1: Average on-site and off-site impacts of water security indicators. Values for the reference scenario without SLM are the absolute values. All other values are differences with respect to the reference without SLM and are accompanied with percentages in parentheses. Values marked in bolt are significantly different ($p < 0.05$). Adapted from Eekhout and de Vente (2019).

Scenario	On-site indicators		Off-site indicators		
	Plant water stress (-)	Hillslope erosion (Mg km ⁻² yr ⁻¹)	Reservoir inflow (Hm3)	Flood discharge (m ³ s ⁻¹)	Sediment yield (Gg yr ⁻¹)
ref.	0.64	3.6	815.4	6.3	1301
ref. + SLM	-0.03 (-4.2)	-1.5 (-40.9)	-119.5 (-14.7)	-0.8 (-12.2)	-90.9 (-7.0)
S1	0.04 (5.5)	1.7 (46.5)	199.3 (24.4)	1.9 (29.6)	96.9 (7.5)
S2	0.03 (5.3)	1.9 (53.1)	240.4 (29.5)	1.6 (25.2)	39.4 (3.0)
S3	0.04 (5.9)	2.0 (55.0)	234.6 (28.8)	1.9 (29.8)	45.4 (3.5)
S4	0.09 (13.4)	1.2 (33.7)	53.0 (6.5)	0.0 (0.4)	-436.6 (-33.6)
S1 + SLM	0.01 (1.6)	-0.4 (-11.2)	66.3 (8.1)	0.8 (13.6)	-23.0 (-1.8)
S2 + SLM	0.01 (0.8)	-0.4 (-11.2)	93.3 (11.4)	0.5 (7.7)	-84.8 (-6.5)
S3 + SLM	0.01 (1.3)	-0.2 (-5.3)	88.6 (10.9)	0.8 (13.0)	-82.4 (-6.3)
S4 + SLM	0.06 (9.5)	-0.7 (-18.8)	-76.3 (-9.4)	-1.0 (-15.5)	-538.8 (-41.4)

Discussion

Our results show that climate change significantly affects hydrology, soil erosion and water security in a large catchment, representative for many Mediterranean climate regions. The most important climate change signal in the study area is an increase of extreme precipitation and frequency of dry spells. The annual precipitation sum is projected to change only slightly for scenarios S1-S3, but more severely for scenario S4, with a catchment average reduction of 18 %. The change in precipitation frequency and intensity causes a redistribution of water, defined by a significant increase of surface runoff and decrease of soil moisture content (Figure 1, middle panel). On-site, this leads to significantly increased plant water stress and hillslope erosion. The off-site impacts include increased reservoir sediment yield (n.s.) and a significant increase of reservoir inflow and flood discharge for most subcatchments in scenarios S1-S3. For the most extreme climate scenario (S4), we found no significant changes for reservoir inflow though due to the stronger decrease in precipitation sum.

Considering the potential of SLM for climate change adaptation, our results demonstrate that SLM significantly reduces both the on-site and the off-site impacts of climate change on soil erosion and water security. Under moderate climate change conditions (scenarios S1-S3), SLM can entirely reverse the climate change impacts or leads to non-significant changes with respect to the reference scenario, with a

minor increased plant water stress (n.s.) and a decrease of hillslope erosion (n.s.) compared to the reference scenario without SLM. Furthermore, a non-significant increase of reservoir inflow and flood discharge is projected, while reservoir sediment yield slightly decreases (n.s.).

Under the more extreme climate change scenario (S4), implementation of SLM also strongly reduces the severity of impacts, however, it does not take them away entirely and still results in a significant negative impact for crucial water security indicators (Table 1). While plant water stress still increases significantly, flood discharge, hillslope erosion and sediment yield reduce, which is the combined effect of strongly reduced annual precipitation and implementation of SLM resulting in soil water retention and erosion prevention. The consequence of these findings is that current rainfed and irrigated agriculture as well as natural vegetation will suffer from increased water shortage and may become unsustainable under future extreme climate conditions (Leon-Sanchez *et al.*, 2018). Hence, additional (SLM) measures are required to adapt to these extreme climate conditions.

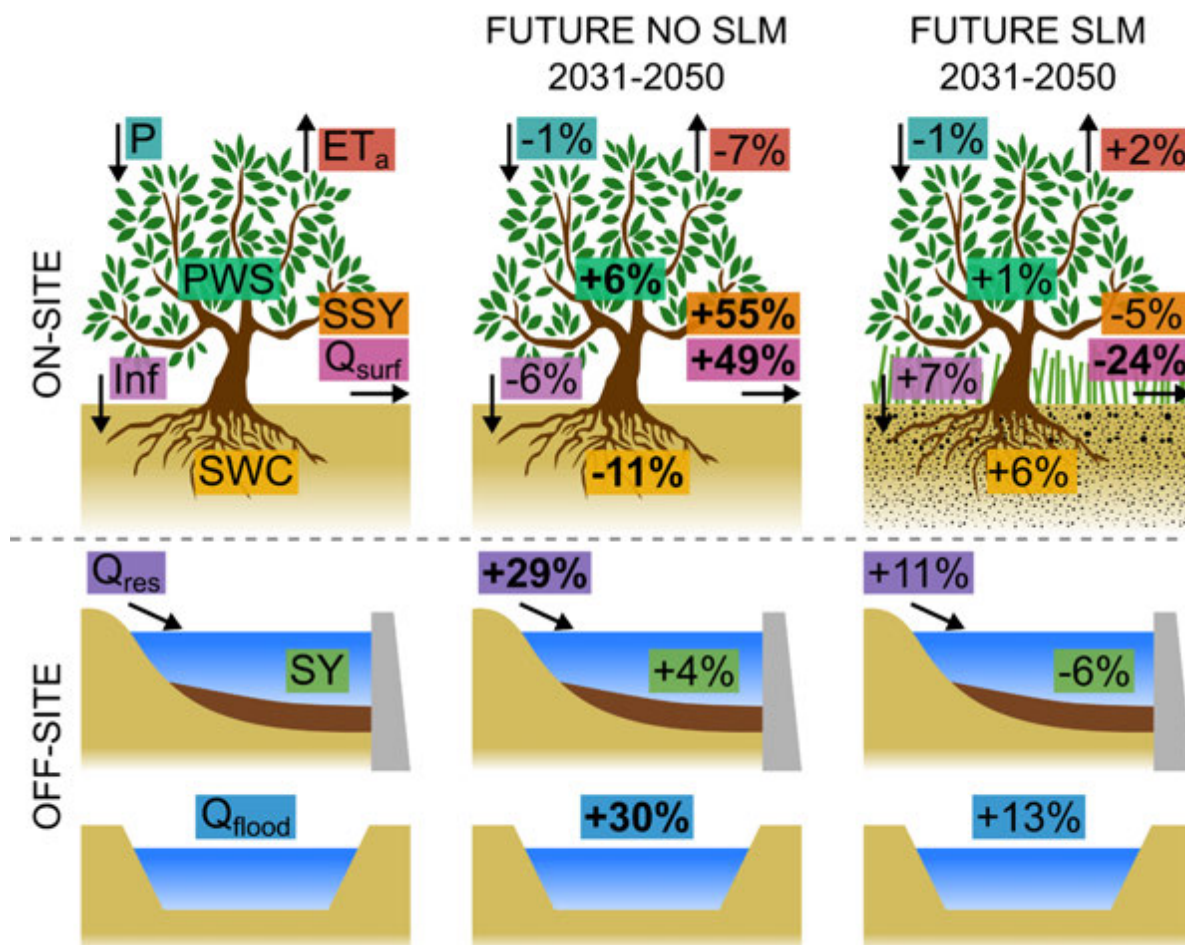


Figure 1: The on-site and off-site impacts of climate change and implementation of SLM. The left panel defines the indicators: precipitation (P), actual evapotranspiration (ET_a), plant water stress (PWS), infiltration (Inf), hillslope erosion (SSY), surface runoff (Q_{surf}), soil water content (SWC), reservoir inflow (Q_{res}), reservoir sediment yield (SY) and flood discharge (Q_{flood}). Adapted from Eekhout and de Vente (2019).

Conclusions

Large-scale implementation of SLM in agricultural lands can significantly reduce the on-site and off-site impacts of climate change on soil erosion and water security. Implementation of SLM in rainfed farming systems almost entirely reverses the on-site and off-site impacts of climate change under moderate climate conditions. Under more extreme reductions of annual precipitation, SLM implementation counteracts negative impacts on soil erosion and reduces the impacts on water security but cannot prevent significant increased plant water stress and reduced water availability. These extreme conditions require additional adaptation measures, considering their interactions and trade-offs regarding water security.

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References

- Almagro, M., de Vente, J., Boix-Fayos, C., García-Franco, N., Melgares de Aguilar, J., González, D., Solé-Benet, A. & Martínez-Mena, M.** 2016. Sustainable land management practices as providers of several ecosystem services under rainfed Mediterranean agroecosystems. *Mitigation and Adaptation Strategies for Global Change*, 21(7): 1029-1043.
- Eekhout, J.P.C., Terink, W. & de Vente, J.** 2018. Assessing the large-scale impacts of environmental change using a coupled hydrology and soil erosion model. *Earth Surface Dynamics*, 6(3): 687-703.
- Eekhout, J.P.C., Hunink, J.E., Terink, W. & de Vente, J.** 2018a. Why increased extreme precipitation under climate change negatively affects water security. *Hydrology and Earth System Sciences*, 22(11): 5935-5946.
- Eekhout, J.P.C. & de Vente, J.** 2019. Assessing the effectiveness of Sustainable Land Management for large-scale climate change adaptation. *Science of the Total Environment*, 654: 85-93.
- León-Sánchez, L., Nicolás, E., Goberna, M., Prieto, I., Maestre, F.T. & Querejeta, J.I.** 2018. Poor plant performance under simulated climate change is linked to mycorrhizal responses in a semi-arid shrubland. *Journal of Ecology*, 160(3): 960-976.