Deliverable 8.4 – Integrated Soil Quality Assessment - Good Quality Soils Support Environmental Protection, Climate Action and Rural Development: The iSQAPER Tool Kit - H2020 Research Conclusions for Policy Makers

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The iSQAPER Tool Kit - H2020 Research Conclusions for Policy Makers

Key Points

1. High quality, healthy soils can perform many production, ecosystem and climate regulation functions. The quality of agricultural soils in particular is decreasing and is of concern at international level. **Better understanding soil quality, its protection and improvement can support a transition to a resilient and sustainable rural economy**.
2. The heterogeneity of soil types, climate zones and farming systems means that soil quality assessment and management needs to target location-specific soil functions or soil threats. **Effective soil assessment needs to take account of both environmental conditions and land management techniques**, **and data needs to be collected and collated to better enable this**.
3. Soil quality is multifaceted. Assessments of soil condition and policy tools to promote improvement must reflect this. **Policy goals should focus on balancing the soil's functions, and not single out one function alone**.
4. **Policies need to be developed that promote soil quality as an integral part of agriculture's economic and environmental resilience**. Within the EU the Common Agricultural Policy (CAP) is central to the ability to address soil quality questions. While actions under the CAP are important in their own right, the CAP is also key to operationalising other policy goals highly relevant to soil quality delivery including biodiversity, climate regulation and water protection.

The iSQAPER Tool Kit – A New, Interconnected Approach to Soil Quality Assessment

iSQAPER has developed a 'tool kit' that can be used to help policy makers, researchers and land managers to better monitor and assess soils at local, regional and continental scales, for better decision making and improved soil quality. These tools should be incorporated in the European Green Deal policy architecture in order to better account for the crucial role soil quality.

1. **A Set of Soil Quality Indicators** - To assess soil quality, an indicator set consisting of chemical, physical and biological indicators is recommended with guidance for the interpretation of indicator values. In addition to well-established indicators,[1] promising novel ones include labile carbon and soil biological indicators.[2]
2. **In Field Soil Assessment – Empowering Farms and Land Users** - Soil Assessment commences by observations in the field, offering valuable real time insights. Visual Soil Assessment (VSA) combined with simple in-field assessment techniques has been demonstrated under iSQAPER to provide a reliable basis for the on-going evaluation of key soil quality parameters at the farm level. Under iSQAPER a manual has been developed[3] to determine how to robustly assess the impact of agricultural management practices on soil quality using VSA.
3. **<u>The SQAPP (smart phone app)</u> – Integrating soil and landscape data to make recommendations on-farm** – presents an overview of an unprecedented number of soil quality and soil threat indicators in a single app for any location in the world based on global data. For each indicator, the app user can benchmark conditions in their field against all locations featuring a similar combination of climate and soil type. Through reviewing and revising these data (e.g. with data from soil samples taken in situ) and specifying a few conditions at the field level, the app user subsequently receives recommendations about practices to integrally improve those aspects of soil quality in which their field performs below-average.
4. **Informed Decision Making - the Adoption of Improved Agricultural Management Practices in Europe** - A great deal of soil quality monitoring is done, but there is a need for this data to be more systematically linked to Agricultural Management Practices (AMPs). Results from long-term experiments as well as farm surveys reveal that certain AMPs such as reduced tillage, organic agriculture, organic matter inputs and crop rotation positively affect soil quality, but with trade-offs between different ecosystem services.[4] Tailored combinations of AMPs are shown to be more effective than individual solutions.
5. **Modelling and scenario analysis** completed on upscaling AMP adoption has identified that targeted intervention focusing on the most vulnerable regions can produce dramatic improvements in soil quality and associated ecosystem services.

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[1] Else K. Bünemann, Giulia Bongiorno, Zhanguo Bai, Rachel E. Creamer, Gerlinde De Deyn, Ron de Goede, Luuk Fleskens, Violette Geissen, Thom W. Kuyper, Paul Mäder, Mirjam Pulleman, Wijnand Sukkel, Jan Willem van Groenigen and Lijbert Brussaard. (2018) Frequently proposed soil quality indicators. https://bit.ly/2CnsuAK

[2] Bongiorno, G. (2020) Assessing soil quality in agro-ecosystems: For reversing soil degradation and enhancing soil Multifunctionality. https://bit.ly/37Qao68

[3] Alaoui, A, Lúcia Barão, Carla S.S. Ferreira, Gudrun Schwilch, Gottlieb Basch, Fuensanta Garcia-Orenes, Alicia Morugan, Jorge Mataix-Solera, Costas Kosmas, Matjaž Glavan, Brigitta Szabó, Tamás Hermann, Olga Petrutza, Vizitiu Jerzy Lipiec, Magdalena Frąc, Endla Reintam, Minggang Xu, Jiaying Di, Hongzhu Fan, Wijnand Sukkel, Julie Lemesle, Violette Geissen, Luuk Fleskens. (2020). Visual Assessment of the Impact of Agricultural Management Practices on Soil Quality. Agronomy Journal. https://acsess.onlinelibrary.wiley.com/action/downloadSupplement?doi=10.1002%2Fagj2.20216&file=agj220216-sup-0001-SuppMat.pdf

[4] Bai, Z., Caspari, T., Gonzalez, M. R., Batjes, N. H., Mäder, P., Bünemann, E. K., … Tóth, Z. (2018). Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China. *Agriculture, Ecosystems & Environment*, 265, 1–7. https://doi.org/10.1016/j.agee.2018.05.028

Quality Soils – Supporting the Transition to a Resilient and Sustainable Economy

Soils perform many production and ecosystem and climate regulation functions. The quality of agricultural soils (in particular arable soils) is decreasing and is of concern both for the delivery of environmental, development and economic and social goals. According to the European Environment Agency, "if we continue using this resource as we currently do, we will also reduce soil's ability, among others, to produce enough feed and food fit for human consumption."[2] The EEA's State and Outlook for the European Environment Report for 2020 assesses the condition of soils in Europe to be deteriorating, and not on track to meet environmental goals in the sector for either 2020 and 2030, partly as a result of intensive agriculture.[5] In its outlook to 2030, the report warns "the underlying drivers of soil degradation are not projected to change favourably, so the functionality of soils is under even more pressure." However, soil's ability to perform ecosystem and climate regulation functions will be central to our ability to deliver the Sustainable Development Goals (SDGs) and the European Green Deal. The transformation of the agricultural sector to provide for sustainable food production and the promotion of a successful bioeconomy will be an important part of these strategies (see figure 1).

"**Soil Quality** is the capacity of a soil to function within ecosystem and land-use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran and Parkin, 1994). A soil of good quality "has **the capacity to fulfil multiple functions**, such as promoting plant growth, preventing water pollution, growing food, promoting biodiversity, sequestering carbon, and many others, within the boundaries given by site conditions" Bünemann, E. K. et al. (2018) .

Improving soil quality can reduce inputs of artificial fertilisers, increase crop pathogen control, promote soil carbon sequestration, increase soil water retention, promote biodiversity and in so doing increase resilience to future climate change. To deliver change it is necessary to assess our soil's current condition, understand what parameters need improvement, make informed land management choices and evaluate the impact of that change. To perform this soil quality assessment, it is critical to understand the status quo, the trajectory of change and how to promote continual improvement over time.

The heterogeneity of soil types, climatic conditions, land use, and farming systems necessitates that soil quality assessment allows for location-specific information to be developed to inform management choices that are differentiated and tailored to best address location specific challenges. Critically, any assessment and soil monitoring system needs to combine information on environmental conditions and knowledge about existing land management to support improved decision making.

[5] European Environment Agency. (2019b) The European Environment – state and outlook 2020. https://www.eea.europa.eu/publications/soer-2020/chapter-05_soer2020-land-and-soil/view

Under iSQAPER new maps developing pedoclimatic zones as a basis for examining soil questions were created.[6] Data connecting land management decisions to soil quality often remains absent or unattributed spatially. This means our understanding of the extent of adoption of land management practices, the interaction with soil characteristics and the consequences for soil quality are currently difficult to analyse. This is slowing the pace of scientific progress and limiting policy makers' ability make informed choices. In addition, it impedes social learning about best management practices at European and international level.

Soil quality is multi-faceted, it cannot be achieved by the delivery of a single parameter or single goal. It is about delivering soils that, through their characteristics allow multiple environmental and production goals to be achieved collectively. This is important to consider in the context of future policy action on soils, in order not to focus on the opportunities through a single lens i.e. maximising their carbon storage for climate, while failing to focus on their broader water quality, climate adaptation and biodiversity roles or ignoring their importance in biomass production or cost-effectiveness considerations. While heterogeneous, the achievement of soil quality at scale requires an integrated intervention, including policy support, but also improved assessment protocols and monitoring regimes.

Developing Policies that Promote Soil Quality and Agricultural Resilience

Results from long-term experiments as well as farm surveys completed under iSQAPER have identified that key management practices or land management combinations reviewed have a predominantly positive impact on soil quality. Reduced tillage, organic agriculture, organic matter inputs and crop rotation were all found to positively affect soil quality. In some cases there may be trade-offs between different ecosystem services, highlighting the importance of tailoring management to local conditions and baselines.[7] However, recognising these interventions and implementing them coherently across arable land would represent significant steps towards supporting improved soil quality. In general, the AMPs have a variety of synergies across different sustainability goals and their deployment would have benefits for biodiversity, climate, and the resilience of the rural economy and landscape.

[6] Tóth, G.. et al. (2016) Hierarchical and multi-scale pedoclimatic zonation. iSQAPER Project Deliverable 2.1, https://bit.ly/311YvZj

[7] Bai, Z., Caspari, T., Gonzalez, M. R., Batjes, N. H., Mäder, P., Bünemann, E. K., … Tóth, Z. (2018). Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China. *Agriculture, Ecosystems & Environment*, 265, 1–7. https://doi.org/10.1016/j.agee.2018.05.028

Within the EU, the Common Agricultural Policy (CAP) is highlighted as central to the ability to address soil quality questions.[8] Actions under the CAP were identified as important in their own right, but they are also key to delivering goals across multiple other policies that are highly relevant for soil protection, for example the Water Framework Directive[9] and the Nitrates Directive. The indicators developed under iSQAPER are very important in this context, but perhaps most important at the Member State and regional level, where the operational context of these policies is developed and monitored. They could be used to make a more concrete link between agricultural subsidies and soil quality, or incorporated in the design of eco-schemes under the CAP in a way that governments could easily monitor.

One important policy issue to highlight is the need for a long-term perspective with regard to soils. It can take many years to reach the potential positive changes needed in soil quality, and policy instruments need to reflect this. Land managers need predictability and long-term certainty in order to implement measures optimally and invest as needed. This should ideally be at the decadal time frame, not just year to year, or CAP cycle to CAP cycle. At the same time, monitoring needs to be adaptable and dynamic enough to give accurate reflections of changes in the shorter to medium term in order to allow for changes in soil management as needed and to reflect the urgency of the sustainability challenges we face, as reported by a number of international monitoring reports from the IPCC, IPBES, and the EEA. iSQAPER has shown that those monitoring tools can already usefully be deployed, but they need to be more systematically accounted for.

The European Green Deal, and its 'Farm to Fork Strategy' (F2F) and '2030 Biodiversity Strategy' spell out a number of ambitious goals which will rely on improved soil quality, and hopefully in turn contribute to it. One of the important aims of the Green Deal is to comprehensively address the challenges of creating holistic, sustainable food systems by recognising the inextricable links between healthy people, healthy societies and a healthy planet. Soil quality is at the centre of these challenges, and needs to be integrated and dealt with coherently between the new CAP, F2F, and Biodiversity Strategy. However, despite this being the case, and to some extent acknowledged as such, it is still the case that in comparison to other environmental threats, the availability of systematic data and monitoring of soils is relatively poor. It can be argued that this lack of data obscures how bad the situation is, and is hindering action in this area.

The central role of soils in climate mitigation and adaptation is also increasingly recognised and must be integrated into the EU's climate policy architecture. However, formal designation of

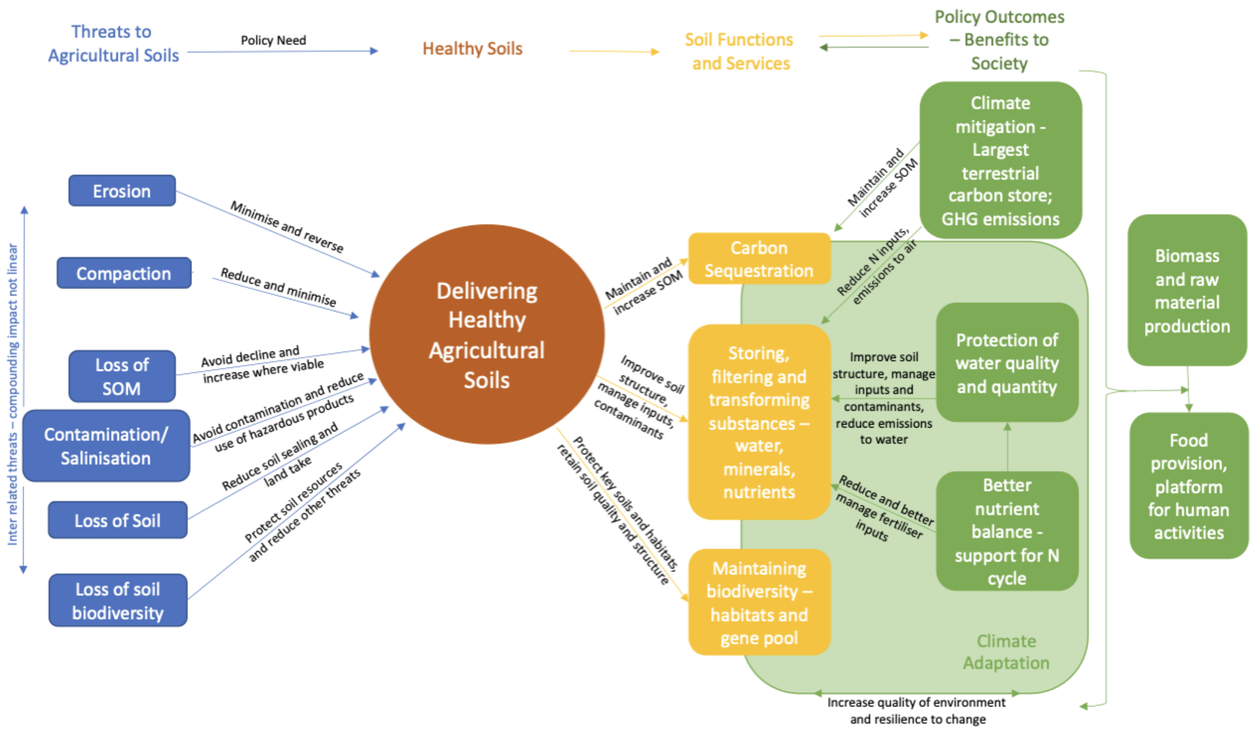
[8] Meredith, S., (2019) Getting to the roots of sustainable land management: A briefing on the Common Agricultural Policy in the EU Post-2020, Briefing for iSQAPER by IEEP. https://ieep.eu/publications/policy-brief-getting-to-the-roots-of-sustainable-land-management

[9] Farmer, A., (2020) Protecting Europe's soils, protecting Europe's water bodies? EU water law and its ability to support soil protection, Briefing for iSQAPER by IEEP. https://ieep.eu/publications/policy-brief-eu-water-law-and-its-ability-to-support-soil-protection

policies and high-level strategies for carbon sequestration in arable soils is inconsistent and quite weak in some Member States. Enhanced monitoring and assessment will be important for the future implementation of credible climate policies in the agricultural sector.

The ISQAPER project has developed a 'tool kit' which can be helpful in implementing this integration. Details are provided below.

Figure 1 – Determining Policy Needs and Intervention Points for Delivering Healthy Soils, Effective Soil Functionality for Land Managers and Society



The iSQAPER Tool Kit – A New, Interconnected Approach to Soil Quality Assessment

'Harmonised, representative soil monitoring across Europe is needed to develop early warnings of exceedances of critical thresholds and to guide sustainable soil management' EEA, SOER 2020[10]

Element 1 - A Holistic Set of Soil Quality Indicators

Soils perform a multitude of functions, and soil quality assessment is most useful when explicitly targeting specific soil functions or soil threats[11]. There is no universal indicator of soil quality, rather

[10] European Environment Agency, (2019), The European environment — state and outlook 2020, https://www.eea.europa.eu/soer/2020/

[11] Bünemann, E. K., Bongiorno, G., Bai, Z., Creamer, R. E., De Deyn, G., de Goede, R., Fleskens, L., Geissen, V., Kuyper, T. W., Mäder, P., Pulleman, M., Sukkel, W., van Groenigen, J. W., & Brussaard, L. (2018). Soil quality – A critical review. Soil Biology and Biochemistry, 120, 105–125. https://doi.org/10.1016/j.soilbio.2018.01.030

soil quality is best assessed by a combination of indicators tackling soil physical, chemical and biological properties. Importantly, soil quality assessment needs to provide a clear interpretation of indicator values, and optimum values are site-specific, depending on pedo-climatic conditions as well as land use.

In iSQAPER, the most commonly used soil quality indicators were identified.[11] To support better assessment of soil quality, both laboratory and visual indicators were tested in long-term field experiments[12] as well as on-farm.[3] In addition to well-established indicators, the iSQAPER project assessed the relevance of novel indicators including labile carbon and soil biological indicators with particular attention to responsiveness to changes.[13]

Developing more responsive indicators – Understanding Change in Soil Quality and Soil Carbon Associated with Land Management - Some of these novel indicators can help to monitor soil quality in a more responsive way than has been possible until present, with indicators that can reliably demonstrate changes over shorter time periods than has been possible until now. An important outcome was that labile carbon is not only sensitive to soil management, but also closely related to various soil processes and ecosystem functions, such as nutrient cycling via microbial activity, erosion control via soil aggregation, disease regulation via soil suppressiveness, and climate regulation via carbon sequestration.[14,12] The determination of labile C as permanganate oxidizable carbon (POXC) is relatively cheap, fast and easy, and a much more informative alternative over the short term when compared to the traditional total organic carbon (TOC) indicator. When defined by standardized protocols, the novel indicator permanganate oxidizable carbon (POXC) can therefore be recommended to be included in soil quality assessment schemes.[2]

Element 2 – In Field Soil Assessment – Empowering Farms and Land Users

Soil Assessment can start relatively simply “in field”, offering valuable real-time insights. Visual Soil Assessment (VSA) combined with simple in-field assessment techniques have been demonstrated under iSQAPER to provide a reliable basis for the on-going evaluation of key soil quality parameters at the farm level[15]. On-farm soil assessments are a useful first step in

[12] Giulia Bongiorno, Joeke Postma, Else K. Bunemann, Lijbert Brussaard,
Ron G.M. de Goede, Paul Mader. (2019) Soil suppressiveness to Pythium ultimum in ten European long-term field experiments and its relation with soil parameters. Soil Biology and Biochemistry 133 174–187.
[13] Bongiorno, G. (2020) Novel soil quality indicators for the evaluation of agricultural management practices: a biological perspective. Front. Agr. Sci. Eng. 2020, 7(3): 257–274. https://doi.org/10.15302/J-FASE-2020323
[14] Bongiorno, G., Bünemann, E. K., Oguejiofor, C. U., Meier, J., Gort, G., Comans, R., Mäder, P., Brussaard, L., & de Goede, R. (2019). Sensitivity of labile carbon fractions to tillage and organic matter management and their potential as comprehensive soil quality indicators across pedoclimatic conditions in Europe. Ecological Indicators, 99, 38–50. https://doi.org/10.1016/j.ecolind.2018.12.008
[15] Alaoui, A, Lúcia Barão, Carla S.S. Ferreira, Gudrun Schwilch, Gottlieb Basch, Fuensanta Garcia-Orenes, Alicia Morugan, Jorge Mataix-Solera, Costas Kosmas, Matjaž Glavan, Brigitta Szabó, Tamás Hermann, Olga Petrutza, Vizitiu Jerzy Lipiec, Magdalena Frąc, Endla Reintam, Minggang Xu, Jiaying Di, Hongzhu Fan,

understanding soil quality *in situ* helping to review impacts of management changes, and critically can provide useful information to a farmer. This can be used to support the selection of the most promising agricultural management practices for enhancing soil quality across European farms.

Under iSQAPER a manual has been developed[12] to determine how to robustly assess the impact of agricultural management practices on soil quality using VSA. The manual can be used as a consistent tool to evaluate soil quality in a standardised and accessible way. It can be used in future to assess soil quality across a wide range of soils and climatic conditions.

Element 3 – The SQAPP – Integrating soil and landscape data to make recommendations on farm

One of the central initiatives of iSQAPER has been the development of the mobile phone app, **SQAPP** (**The iSQAPER Soil Quality Assessment APP**). The SQAPP provides a context-specific score for soil quality and soil threats for a specific locality, enabling users to compare the quality of their soil to the quality in other locations. Most importantly it provides recommendations for the user about the best location-specific management practices to improve the quality of the soil.

This app represents an important breakthrough, providing the user with free access to the best available global soil information, anywhere in the world. The SQAPP provides free and easy access to global soil and landscape data. It provides site-specific interpretation of widely used soil quality indicators, assesses the local threats to soil quality and gives recommendations for management practices that would improve it.[16] App users can either use embedded data or add their own data (ideally based on the indicator set and 'in field' assessment methods set out in elements 1 and 2) to the database to receive tailored recommendations.

SQAPP is a useful tool for a wide variety of user groups including farmers, agri-advisors, researchers and policy makers, all of whom have been involved in its development and evaluation. It can already be used as a decision support tool for land managers and for research purposes. It could be used to help inform local policy and decision makers about relevant initiatives. The app is very easy to use, and gives the user instant data to benchmark

Wijnand Sukkel, Julie Lemesle, Violette Geissen, Luuk Fleskens. 2020. Visual Assessment of the Impact of Agricultural Management Practices on Soil Quality. Agronomy Journal. https://doi.org/10.1002/agj2.20216.
[16] SQAPP Guide for Policy Makers, https://www.isqaper-is.eu/sqapp-the-soil-quality-app/faqs/252-how-can-sqapp-be-used-by-policy-makers

the soil quality in their field of interest to other locations having similar combinations of soil and climate conditions.

Moreover, with further development, SQAPP could evolve into a tool for self-reporting of soil quality data and land management data, filling the earlier-mentioned data gap on management in relation to soil data. This could potentially be a useful monitoring tool applicable in a number of policy areas at Member State and European level.

Element 4 – Informed Decision Making and the Adoption of Improved Agricultural Management Practices in Europe

A great deal of soil quality monitoring is done, but there is a need for this data to be more systematically linked to Agricultural Management Practices (AMPs). Continuous information on AMPs is needed as well as widely available baseline information on soil quality for best monitoring across the EU. An urgent effort is needed to provide more systematic data and monitoring on the link between AMPs and soil quality. Such monitoring should be integrated into standard on-farm reporting requirements.

Results from long-term experiments and farm surveys revealed that AMPs such as minimum soil disturbance, organic agriculture and crop rotation positively affect soil quality, but with trade-offs between different ecosystem services. For example, reduced tillage and organic agriculture typically improve soil organic matter content, soil physical stability and soil as a habitat, but with some yield penalties.[17] Not only the quantity, but also the quality of soil organic matter (SOM) is central to the multi-functionality of soils. Diverse crops and green manures, organic amendments of different recalcitrance[18] (manure, compost, crop residues, plant mulches) impact quality of soil organic matter. It is important to continually assess the effects of different combinations of AMPs in research and farm settings through field trials.

iSQAPER has identified the most promising AMPs and their combinations that improve soil quality.[19] Combinations of two or three AMPs showed greater positive impacts on soil quality than using single applications of AMPs. More specifically, AMP – soil organic matter relationships show the potential benefit of using combinations of cover crop treatments and no-till or minimum-till to preserve or even enhance organic matter in surface soil layers. Cluster analysis showed that the most promising combinations of AMPs having a positive impact on soil quality are composed of crop rotation, mulching and minimum-till. Organic-

[17] Bai, Z., Caspari, T., Gonzalez, M. R., Batjes, N. H., Mäder, P., Bünemann, E. K., … Tóth, Z. (2018). Effects of agricultural management practices on soil quality: A review of long-term experiments for Europe and China. *Agriculture, Ecosystems & Environment*, 265, 1–7. https://doi.org/10.1016/j.agee.2018.05.028

[18] Ie that decompose at different rates

[19] Alaoui et al. (2020)

matter amendments and organic farming were also identified as important tools to fight threats to soil quality.[20]

Element 5 – A regional modelling and scenario tool

Regional modelling of future land use scenarios shows that the expected ('business as usual') scenario is not enough to make significant contributions towards improving the soil environmental footprint. However, a scenario modelling a situation in which policy efforts are focused on improving AMPs in areas where soil threats are more active and soil quality indicators are poorer delivers important benefits in key challenging areas, where the effects greatly improve the soil environmental footprint. Thus, in a situation of insufficient resources, targeting efforts on these areas could make significant overall improvements in soil environmental footprint.[21] However, the effects of an intensification of the rate of implementation of beneficial AMPs as a result of public policies yield substantially higher benefits, due to the combined effect of the improvements to ecosystem services modelled, which reinforce each other. The region that shows the greatest improvement of soil environmental footprint in Europe is Mediterranean-South, while the region that shows the least improvement is the Alpine region.

The impacts of AMPs were more notable when implemented in naturally less fertile soils, such as Podzols and Calcisols. In these soils, AMPs presented higher percentages of positive impacts (90-100%), whereas in other soils with intrinsic high fertility, such as Luvisols and Fluvisols, the positive impacts of AMPs were lower (50-60%). This shows that the site-specific context should be taken into account for efficient implementation of the management strategies, and an urgent approach to "hot-spots" of poor soil quality and deterioration would be justified, although a generalised approach would yield better results.

[20] Bai et al, 2018.
[21] Luis Garrote, David Santillán, Ana Iglesias. (2019) Report on the evaluation of scenarios of changed soil environmental footprint for a range of policy scenarios. ISQAPER deliverable 7.4.

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