Soil quality inventory of Case Study Sites

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Deliverable 5.2 of
iSQAPER
Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience

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Contents

Executive summary

This report is Deliverable (5.2) of the EU-funded project '*Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience*' (iSQAPER).

The aim is to establish an inventory of the current status of soil quality as impacted by the promising agricultural management practices at the case study sites. The specific objectives of the present study are: (i) to select promising AMPs improving soil quality, and (ii) to assess their impacts on soil quality at different study sites in Europe and China. In selected study sites, the most promising AMPs were documented using WOCAT database (www.wocat.net). First results are presented here.

1. Introduction

Agricultural soils are under a wide variety of pressures, including from increasing global demand for food associated with population growth, changing diets, land degradation and associated productivity reductions, potentially exacerbated by climate change impact (Rogger et al., 2017). Restoring the ecological functions and productivity as well as regulation services of a soil, and preventing further degradation can be achieved with appropriate management practices. These practices may reduce the potential negative impacts of extensive monocultures and the use of heavy machinery operations, since they are highly adaptable to the specific conditions where they are applied (e.g., Sarker et al. 2018). Over the last decade, there has been increasing interest on the impact of agricultural management practices on soil organic carbon (SOC), nutrient cycling and storage worldwide (Dalal et al., 2011; Hoyle and Murphy, 2011; Hoyle et al., 2013; Kopittke et al., 2016). The nutrient contents of soil may be maintained or enhanced by appropriate management practices, favoured by additional organic matter inputs or retention into the system. Management practices such as (i) long-term no-till with stubble retention, along with fertilisation in cropping systems, and (ii) mixed crop–pasture and perennial pasture dominated farming systems, are usually recommended to increase or maintain soil organic matter (SOM) and associated nutrients (Dalal et al., 2011; Hoyle et al., 2013). SOM has been considered a ready source of plant available N, P and S, although its mineralization and nutrient release are enhanced by tillage and stubble retention, which varied with soil type (Sarker et al., 2018).

Conservation tillage, including many practices such as tillage with tined tools at depths down to 15–20 cm or direct seeding without prior cultivation, intends to protect the soil surface from crusting and erosion by leaving crop residues and organic matter at the soil surface. Several studies have shown that conservation tillage increases soil carbon stock (Cookson et al., 2008), has positive effects on soil chemical properties in the upper soil layer and contributed to the increase of wheat biomass until tillering stage (Peigné et al., 2018). It enhances the quantity, activity and diversity of soil microorganisms in the upper soil layers (Cookson et al., 2008), as well as earthworm biomass and diversity (Pelosi et al., 2014). It preserves their habitat (burrows), especially anecic burrows, which favour water infiltration and root penetration (Soane et al., 2012). It tends also to increase water-stable aggregates in the uppermost soil layer under conservation tillage compared to ploughing (Holland, 2004; Blanco-Canqui and Lal, 2007). These improvements allow reductions in labour work, energy consumption and machinery costs (Soane et al., 2012).

Maintenance and/or addition of crop residue are also vital to maintain and increase soil C stocks, respectively, and mitigate climate change impacts (Chatterjee, 2013; Dikgwatlhe et al., 2014) through the formation of humus and soil macroaggregates (Alidad et al., 2012; Liu et al., 2014). Regular inputs of crop residues, organic compost or manure can also increase total SOC, based on the balance between C inputs and decomposition processes. This equilibrium level is affected by the types of C inputs to the system and their conversion into stable C in the soil by microbial communities (Kallenbach et al., 2016). Zhao et al. (2018) showed that return of both maize and wheat straw was the best strategy to improve soil structure, SOC and crop yield. But straw return from one crop was sufficient to maintain initial SOC levels, and maybe sufficient for cellulosic feedstocks. However, there are conflicting research on this topic, since some studies have identified negative effects of straw return on soil aggregates (Bossuyt et al., 2001; Soon and Lupwayi, 2012), suggesting that the effect of straw return on soil aggregation in agricultural soils is related to appropriate management practices and climate conditions (Li et al., 2018).

For appropriate management of agricultural soils, decision-makers need science-based, easily applicable, and cost-effective tools to assess soil quality and soil functions. Since practical assessment of soil quality comprises key soil properties and their variations in space and time, providing such tools remains a research challenge.

Soil quality indicators should be selected according to the soil functions of interest and threshold values have to be identified, based on local conditions to generate a meaningful soil quality index. The selection of indicators can be based on experts' opinion, statistical procedures, or a combination of both, to obtain a minimum data set (MDS).

Visual soil assessment (VSA) methodology, based on key indicators and components of soil quality, allows understanding of the impact of agricultural management practices on soil physical, chemical and biological properties. Visual assessment provides an immediate, effective diagnostic tool to assess soil condition, and the results are easy to interpret and understand. It has been used in several countries and explains differences in crop performance and yield resulting from soil type and management (Ball et al., 2013).

The present deliverable is related to the European H2020 iSQAPER project -– Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience. In this framework, 14 study sites covering the major pedo-climatic zones of Europe and China were selected with the aim to consider a large variety of AMPs, soil types and cropping systems. The specific objectives of the present study are: (i) to select promising AMPs improving soil quality, and (ii) to assess their impacts on soil quality at different study sites in Europe and China.

2. General framework

2.1 Case Study Sites:

The impacts of AMPs on soil quality were measured in 14 case study sites, including 10 located in Europe and 4 in China, representative of the major pedo-climatic zones (**Figure 1**). The CSS represent wide agricultural management activities and were chosen because they include promising AMPs that have been shown to improve soil quality (**Table 1**).

2.2 Pedoclimatic zones:

In Europe, the 10 study areas covered 6 out of the 8 climatic zones: Boreal to sub-Boreal (14 plots), Northern sub-Continental (5 plots), Southern Sub-Continental (49 plots), Atlantic (7 plots), Mediterranean Temperate (31 plots) and Mediterranean semi-arid (6 plots). In China, climate variability is higher and only 3 out of 10 climatic areas were investigated: Central Tropical Asia (14 plots), Warm Temperate and Middle (6 plots) Temperate zone (6 plots).

2.3 Farming systems and Agricultural management practices:

The classification of the farming systems used in this study was according to CORINE land cover assessment (European Environment Agency, 2006) and consist of 3 classes; Arable land, permanent crops, fodder crops, root crops, and pastures.

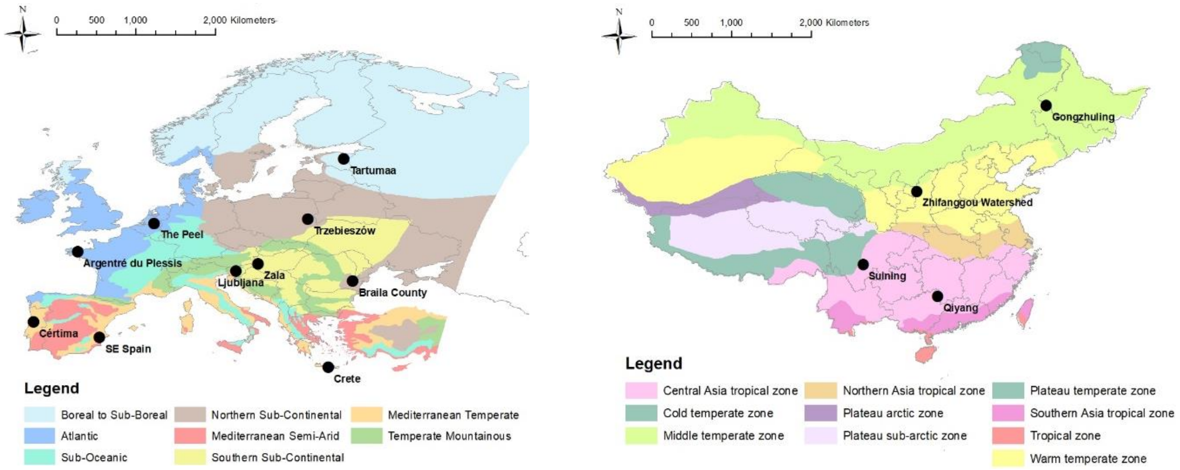


***Figure 1** – Study Site Areas location in Europe and China and distinct climatic zones.*

Based on WOCAT database (www.wocat.net), 18 promising AMPs with potential to improve soil quality were selected (Schwilch et al., 2011) (**Table 1**). Each case study identified at least 3 out of the 18 selected APMs (or combinations thereof). The selection of these AMPs was performed based on the following criteria: (i) management practice implemented for at least 3 years; (ii) at least in 2 different soil types; and (ii) at least in 2 different first level Farming Systems (arable, permanent, grazing). For mixed farming systems, the study site teams were asked to consider the existence of two different farming systems on the same farm, in case it includes both arable cropping and pastures. Additionally, for each AMP plot, the study site teams had to identify 3 related control plots. The idea is to compare the soil quality on a plot where management practices have changed 3 or more years ago with that on a control plot where practices did not change. Both control and AMP plots were located in the same pedo-climatic zone and having comparable soil conditions. In total, 138 sets of paired plots (138 plots with promising AMPs and 138 controls) were considered, with 112 plots located in Europe and 26 in China.

Table 1. *Promising AMPs considered, description, expected impacts/ecological benefits and the corresponding main soil threat targeted by its use (**WOCAT**, **(Schwilch et al., 2011)**).*

AMP list	AMP description	Expected impacts / Ecological benefits
1 - No-till **(Soil Managm.)**	A system where crops are planted into the soil without primary tillage	- Reduces decomposition of OM rates leading to its increase in soil, enhances cycling of nutrients, enhances soil structure and increases water infiltration. - Improves soil biological life including disease and weed suppression.
2 - Min-till **(Soil Managm.)**	Tillage operation with: a) reduced tillage depth; b) strip tillage; c) mulch tillage; or or a combination thereof	- Reduces decomposition of OM rates leading to its increase in soil, enhances cycling of nutrients, enhances soil structure and increases water infiltration. - Improves soil biological life including disease and weed suppression.
3 - Permanent soil cover / Removing less vegetation cover **(Soil Managm.)**	Avoiding a bare or sparsely covered soil exposed to weather conditions (rain, wind, radiation, etc) by ensuring a permanent cover (at least 30% of the soil surface) throughout the year, e.g. through cutting less grass, leaving a volunteer crop or crop residues, etc. (see also cover crops and residue maintenance / mulching)	- Improves infiltration and retention of soil moisture resulting in less severe, less prolonged crop water stress and increases availability of plant nutrients. - Provides source of food and habitat for diverse soil life: created channels for air and water, biological tillage and substrate for biological activity through the recycling of organic matter and plant nutrients. - Increases humus formation. - Reduces the impact of rain drops on soil surface resulting in reduced crusting and surface sealing. - Reduces runoff and erosion. - Reduces wind erosion. - Increases soil regeneration. - Mitigates temperature variations on and in the soil. - Improves the conditions for the development of roots and seedling growth.
4 - Cover crops **(Soil Managm.)**	a) Cover cropping: planting close-growing crops (usually annual legumes), b) Relay cropping: specific form of mixed cropping / intercropping in which a second crop is planted into an established stand of a main crop. The second crop develops fully after the main crop is harvested. Better crop cover: selecting crops with higher ground cover, increasing plant density, etc.	a) Protects soil, between perennials or in the period between seasons for annual crops. N-fixation in case of leguminous crops. b) Continuously covered soil. Reduces the insect/mite pest populations because of the diversity of the crops grown. Reduces the plant diseases. Reduces hillside erosion and protected topsoil, especially the contour strip cropping. Attracts more beneficial insects, especially when flowering crops are included in the cropping system. c) Protects soil against the impacts of raindrops or wind and keeps soil shaded; and increases moisture content.
5 - Residue maintenance / Mulching **(Soil Managm.)**	Maintaining crops residues or spreading of organic (or other) materials on the soil surface.	-Reduces sheet and rill erosion. - Reduces wind erosion. - Maintains or improves soil organic matter content. - Conserves soil moisture. - Provides food and escapes cover for wildlife.
6 - Cross-slope measure **(Soil Managm.)**	Structural measure along the contour to break slope lengths, such as terraces, bunds, grass strip, trashlines, contour tillage	Reduces surface runoff and erosion (increase infiltration capacity).
7 - Measures against compaction **(Soil Managm.)**	a) Breaking compacted soil: e.g. deep ripping, subsoiling (hard pans); Digging the soil up to twice as deep as normally. b) Growing deep rooted plants in the rotation such as: annual alfalfa, beet, sunflower, okra, flax, turnip. c) Controlled traffic farming: is a system which confines all machinery loads to the least possible area of permanent traffic lanes Soil compaction models (considering tire size, inflation pressure, weather and soil conditions) to predict allowable wheel load and soil compaction maps to show how soil compaction varies at different locations and depths across the field	a-b) Looses soil to improve drainage, infiltration, aeration and rooting characteristics, and brings nutrients up from deep below c-d) Minimizes soil damage and preserves soil function in terms of water infiltration, drainage and greenhouse gas mitigation, and (d) provides useful information for decision making process for site-specific applications such as variable deep tillage to benefit from increased timeliness (and reduced management costs)

AMP list	AMP description	Expected impacts / Ecological benefits
8 - Leguminous crop **(Nutrient Managm.)**	A leguminous crop is a plant in the family Fabaceae (or Leguminosae) that is grown agriculturally, primarily for their grain seed called pulse, for livestock forage and silage, and as soil-enhancing green manure. Well-known legumes include alfalfa, clover, peas, beans, lentils, lupins, mesquite, carob, soybeans, peanuts, and tamarind.	- Provides soil with nitrogen and additional nitrogen from chemical fertilizers can be reduced. (See also cover crop and green manure)
9 - Green manure / Integrated soil fertility management **(Nutrient Managm.)**	Green manure is a crop grown to be incorporated into the ground, while the more general term 'integrated soil fertility management' refers to a mix of organic and inorganic materials, used with close attention to context-specific timing and placing of the inputs in order to maximize the agronomic efficiency.	- Increases organic matter content, thereby improving fertility and reducing erodibility. In case of leguminous green manure, tilling it back into the soil allows exploiting the high levels of captured atmospheric nitrogen found in the roots.
10 - Manuring[a] / composting[b] **(Nutrient Managm.)**	a) Manure is organic matter, mostly derived from animal feces (except in the case of green manure, which can be used as organic fertilizer in agriculture). b) Compost is organic matter that has been decomposed and recycled as a fertilizer and soil amendment. Compost is a key ingredient in organic farming.	Contributes to the fertility of the soil by adding organic matter and nutrients, such as nitrogen, that are trapped by bacteria in the soil. b) Improves soil fertility through nutrient content and availability, soil structure and microbiological activity; impacts plant growth and health directly and indirectly.
11 - Crop rotation[a] / Control or change of species composition[b] **(Pest Managm.)**	Practice of alternating the annual crops grown on a specific field in a planned pattern or sequence in successive crop years so that crops of the same species or family are not grown repeatedly on the same field Diversify species in rotation systems or grasslands	a) - Reduces risk of pest and weed infestations. - Improves distribution of channels or biopores created by diverse roots (various forms, sizes and depths). - Improved distribution of water and nutrients through the soil profile. - Allows exploration for nutrients and water of diverse strata of the soil profile by roots of many different plant species resulting in a greater use of the available nutrients and water. - Increases nitrogen fixation through certain plant-soil biota symbionts and improved balance of N/P/K from both organic and mineral sources. Increases humus formation. b) Introduces desired / new species, reduces invasive species, controls burning, residue burning.
12 - Integrated pest and disease management incl. organic agriculture **(Pest Managm.)**	Appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to reduce or minimize risks to human health and the environment.	- Emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.
13 - Water diversion and drainage **(Water Managm.)**	A graded channel with a supportive ridge or bank on the lower side. It is constructed across a slope to intercept surface runoff and convey it safely to an outlet or waterway	- Reduces hazard towards adverse events (floods, storms,…), reduces soil waterlogging
14 - Irrigation management **(Water Managm.)**	Controlled water supply and drainage: mixed rainfed – irrigated; full irrigation; drip irrigation	- Improves water harvesting; increased soil moisture; reduces evaporation; improves excess water drainage; recharge of groundwater
15 - Major change in timing of activities **(Crop Managm.)**	Adaptation of the timing of land preparation, planting, cutting of vegetation according weather and climatic conditions, vegetation growth, etc.	- Reduced soil compaction, soil loss, improved biomass, increased biomass, increased soil OM
16 - Layout change according to natural and human environment/needs **(Crop Managm.)**	eg exclusion of natural waterways and hazardous areas, separation of grazing types; increase of landscape diversity.	- Reduces surface runoff and erosion, increases biomass, nutrients and soil OM, controls pests and diseases
17 - Area closure / rotational grazing **(Crop Managm.)**	Complete or temporal stop of use to support restoration	- Improves vegetative cover, reduces intensity of use, and soil compaction and erosion.

AMP list	AMP description	Expected impacts / Ecological benefits
18 - Change of land use practices / intensity level **(Crop Managm.)**	eg change from grazing to cutting (for stall feeding), from continuous cropping to managed fallow, from random (open access) to controlled access (grazing land), from herding to fencing, adjusting stocking rates.	- Increases biomass, nutrient cycling, soil OM, improves soil cover, beneficial species (predators, earthworms, pollinators), biological pest / disease control, and increases / maintains habitat diversity. - Reduces soil loss, soil crusting/sealing, soil compaction, and invasive alien species.

2.4 Soil quality indicators:

In order to assess the impact of AMPs on soil quality, 11 soil quality variables based on a visual soil assessment methodology were selected based on extensive literature review (e.g. Shepherd, 2000) (**Table 2**). For each variable, clear and precise instructions were compiled in a manual. A newly developed infiltrometer was used to easily assess the soil infiltration capacity in the field and to investigate hydrodynamic flow processes (Alaoui et al., 2018).

Table 2*. List of the variables used to assess soil quality. Indicators 1 and 2 provide general information, 3 to 8 are derived from visual soil assessment (VSA) methodology, and 9 to 11 are based on measurements.*

N^o.	**Soil quality indicator**	**Soil threats addressed**
1	Susceptibility to Wind and Water Erosion	Erosion
2	Surface ponding (under cropping)	Soil compaction
3	Presence of a cultivation pan	Subsoil compaction
4	Soil Colour	OM decline
5	Soil porosity	Soil compaction
6	Soil structure and consistency	Soil compaction
7	Soil slaking test (soil stability)	Erosion
8	Biodiversity (earthworm density)	Biodiversity decline
9	pH	Acidification
10	Infiltration rate / Penetration resistance	Soil compaction
11	Labile organic carbon	Organic carbon decline

It is worth to mention that the indicators selected to evaluate soil quality are mainly related to soil structure (3 – 8 and 10) since they are based on VSA methodology. In this report, soil quality concerns mainly soil structure. We have established a new questionnaire to cover biological properties for the assessment of soil quality for season 2018. A quantitative investigation of soil quality in terms of physical, chemical and biological will be done by WP6 during season 2018.

For the evaluation of soil quality, a qualitative score was established for the 11 variables according to 3 conditions: good, moderate, and bad, illustrated with standardized Photos serving as references and corresponding to scores ranging from 2 (good conditions) to 0 (bad conditions). The improvement in soil quality was checked through the comparison between the AMP plot and the control. In the case, at least a single variable shows a better score of soil quality in a plot with AMP (in comparison to the control), a soil quality improvement was considered. In case of better variable scores in the control, traducing better soil quality, the impact of AMP was considered as negative effect. If the scores were similar, the AMP was assumed to have no impact. The inventory and the scoring of soil quality were done together with land users, between July and December 2016, for all study sites under the constrains of carrying out the assessment of the paired AMP plot – control to insure comparable soil conditions.

The farmers were requested to express their own opinion with regard to the variables that have meaning for soil quality within the list we proposed (**Table 2**). We then compared their own variables with the ones that have been shown to improve soil quality in all study sites.

3. Results

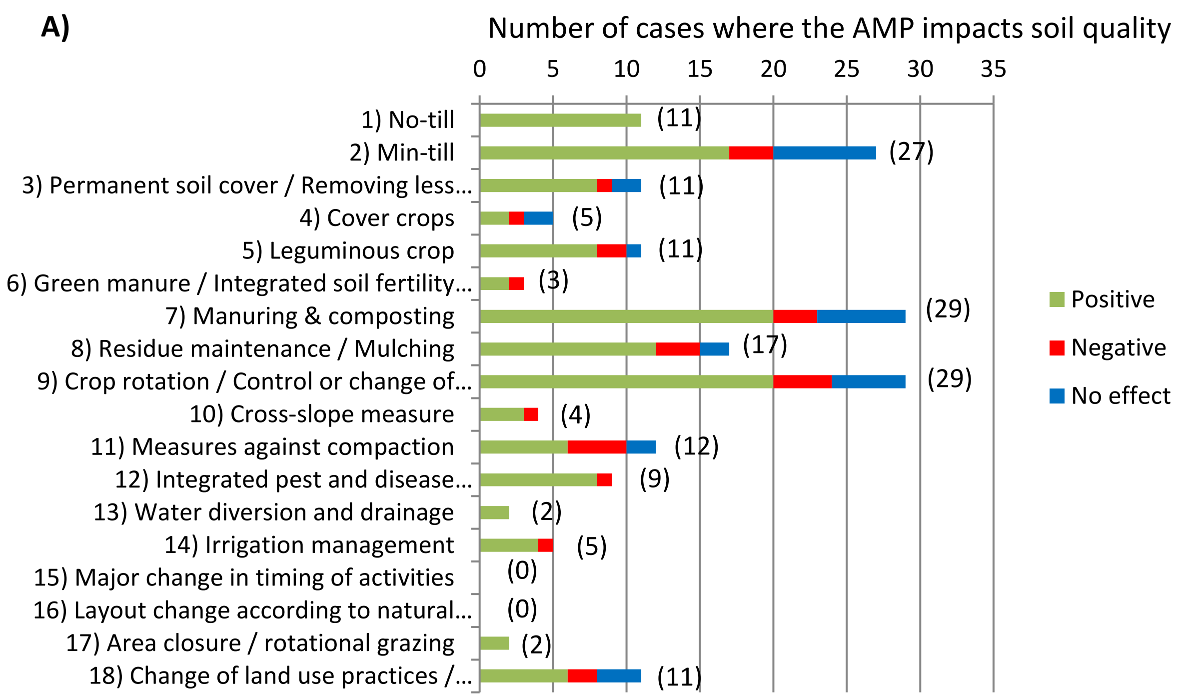
3.1 Soil quality inventory

Results show that among 138 sets of paired plots, 104 pairs (75.4 %) show a positive impact of promising agricultural management practices on soil quality, 20 pairs (14.5 %) do not show any difference in soil quality between soils under promising practices and soils in the control plots, and the remaining 14 plots (10.1 %) show an inverse effect. When considering Europe, 82 sets of paired plots (73.2%) (22 or 84.6%, for China) show a positive impact, 19 pairs (17%) (1 or 3.8% for China) do not show any difference in soil quality, and the remaining 11 pairs (9.8%) (3 or 11.5% for China) show an inverse impact (**Table 3**).

Table 3. *Summary of the impact of the implementation of the selected AMPs on soil quality in Europe and China.*

Impact	Total plots (138)		Plots in Europe (112)		Plots in China (26)	
	Absolute value	(%)	Absolute value	(%)	Absolute value	(%)
Positive	104	75.4	82	73.2	22	84.6
No effect	20	14.5	19	17.0	1	3.8
Inverse	14	10.1	11	9.8	3	11.5

In Europe, the most promising AMPs that have been shown to positively impact soil quality are “crop rotation /control or change of species composition”, “manure and composting”, “minimum tillage” and “no-till” (**Fig. 2A**). For China, the most promising AMPs having positively impacted soil quality are “residue maintenance / mulching”, “manure and composting”, “integrated pest and disease management” and “green manure / integrated soil fertility” and irrigation management” (**Fig. 2B**).



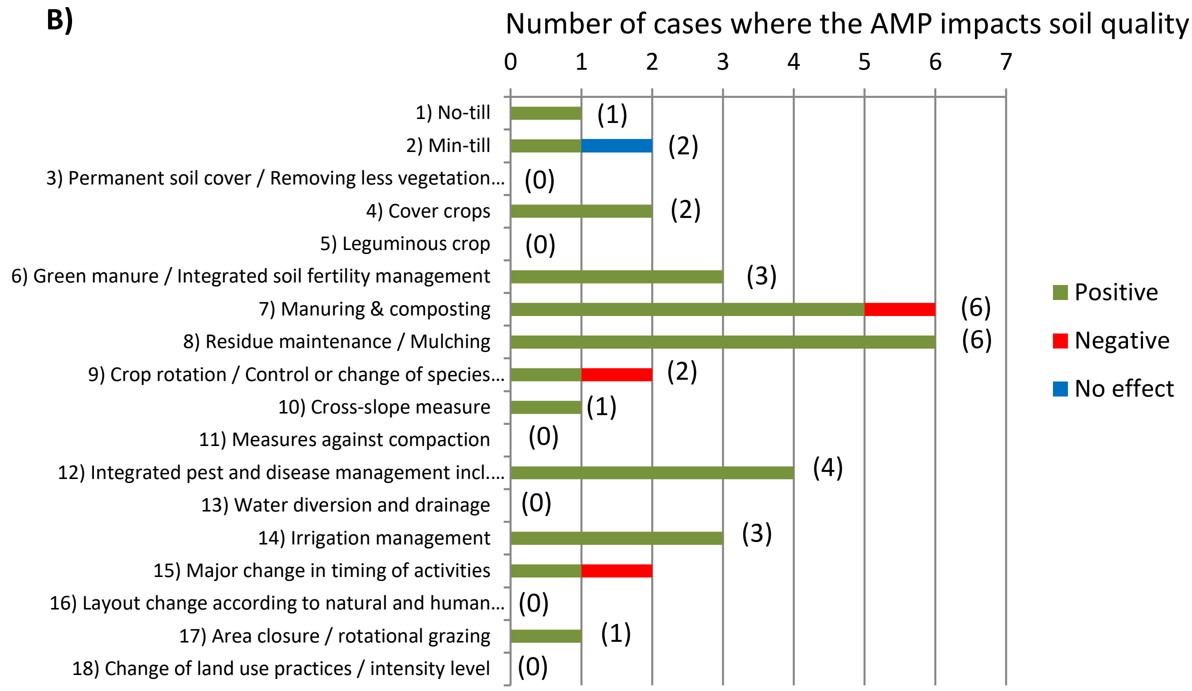


Figure 2. *Impact of the agricultural management practices (AMPs) on soil quality A) in Europe, and B) in China; total numbers of AMPs considered is given in brackets*

When considering only the soil types that are at least 10 times represented over all study sites (Antrosol, Fluvisols, Cambisols, Regosols, Calcisols, Luvisols, and Podzols), AMPs with positive impacts on soil quality are implemented mostly in Podzols (100%), Calcisols (91%) Regosols (84.6%), Antrosols (71.4%), Luvisols (70.6%), Cambisols (62.5%), and finally Fluvisols (58%) (**Table 4**).

Table 4. *Impacts of agricultural management practices (AMPs) on soil quality in the most investigated soil types*

Soil types	Positive impacts (%)	No effects & Negative impact (%)	Total number of soil types considered (-)
Antroposol	71.4	28.6	14
Fluvisol	58	42	19
Cambisol	62.5	37.5	32
Regosol	84.6	15.4	13
Calcisol	91	9	11
Luvisol	70.6	29.4	17
Podzol	100	0	10

Within these soils, AMPs with negative and no effect on soil quality are implemented mostly in Cambisols (37.5 %), Fluvisols (42 %) and Luvisols (29.4 %). The non-detectable effect of the promising practices on soil quality are due to type of tillage management, soil type and fertility that mask the effect of management practices on soil. Furthermore, the timing of the assessment may be an important parameter. VSA methodology should be performed in the middle of growing period of a certain crop or crop type. Certain soils, such as Fluvisols, are so fertile that only small differences in harvest time, tillage or crop type can cause changes in scores. Some types of management (min tillage) can explain the low number of earthworms present throughout soil profile due to the fact that organic matter is not ploughed deeper into the soil.

Results show that the most sensitive variables to soil quality are these describing soil structure, such as soil structure and consistency, soil porosity, aggregate stability reflected by the slaking test, and soil colour, followed by soil compaction indicated by the presence of a cultivation pan (**Fig. 3**). Taking into account some criteria regarding the assessment (e.g., friendly use, sensitivity to different soil types) and the feedbacks of the study site teams, the indicators selected for the evaluation of the impact of the AMPs on soil quality appear to be appropriate for soils of all study sites except for very fertile soils (**Fig. 3**).

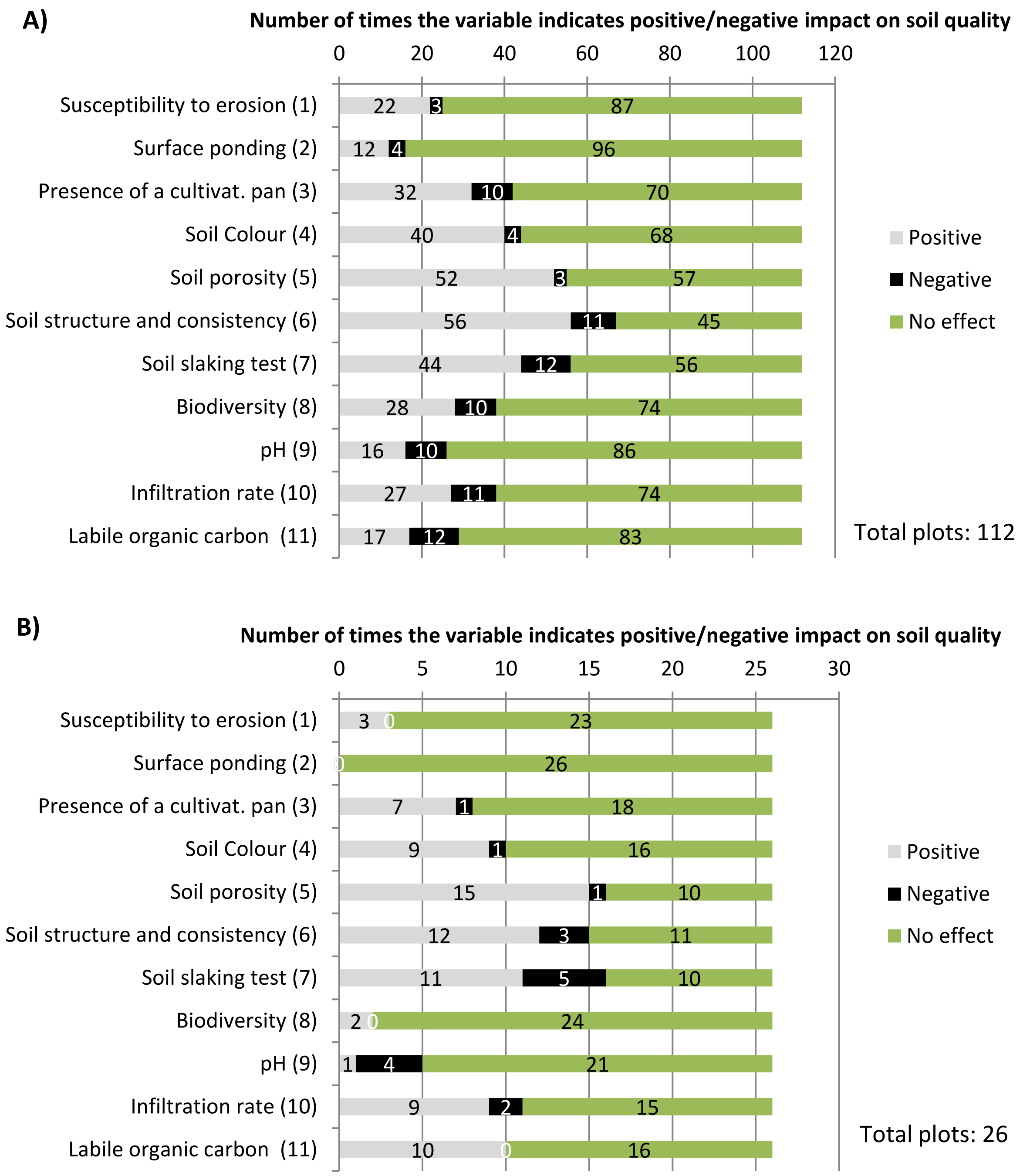


Figure 3. *Number of times the variable indicates positive/negative impact on soil quality in A) Europe (n=112), and in B) China (n=26); positive means an improvement of soil quality, negative means an inverse effect*

In Europe, the variables selected by the farmers to evaluate soil quality are generally in accordance with researchers' selection, but with fewer interests on soil colour, biodiversity and infiltration rate (**Fig. 4**). Similar opinion was also observed in China, except for biodiversity which was not selected by the farmers. **Figure 5** shows that the three main variables selected by the farmers for the evaluation of soil quality are related to soil structure, namely soil porosity (5), soil structure and consistency (6), and soil slaking test (7), respectively).

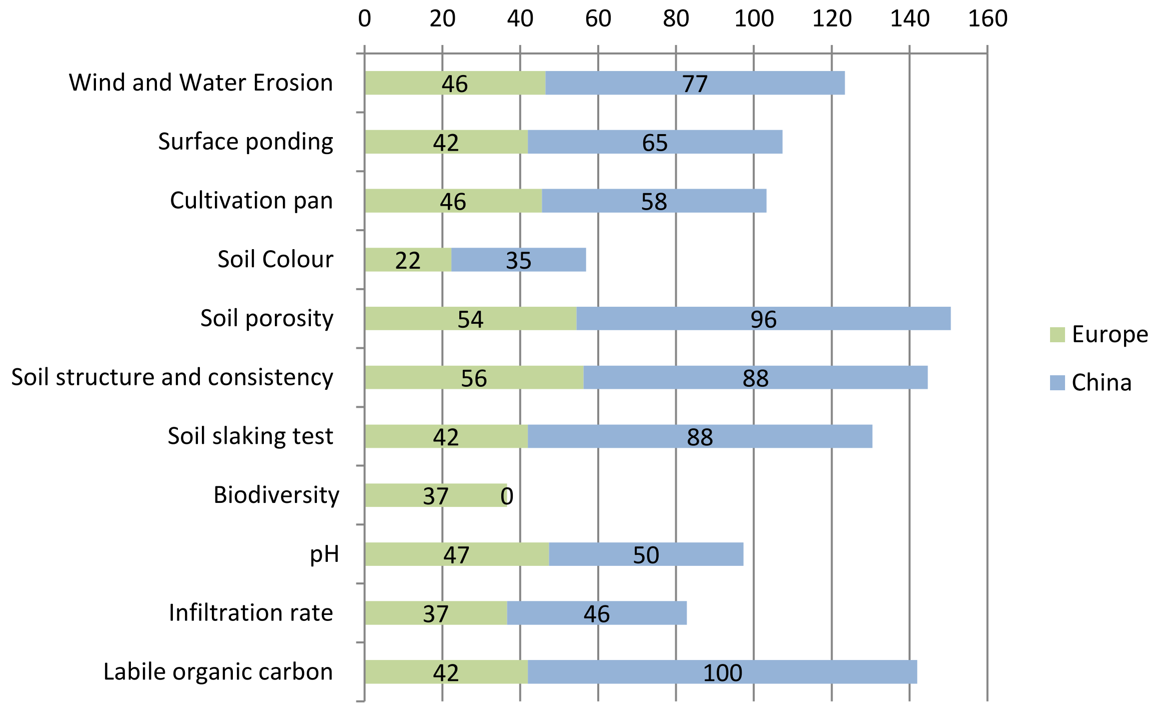


Figure 4. *Indicators proposed by the farmers to evaluate soil quality (number of the interviewed farmers for Europe and China)*

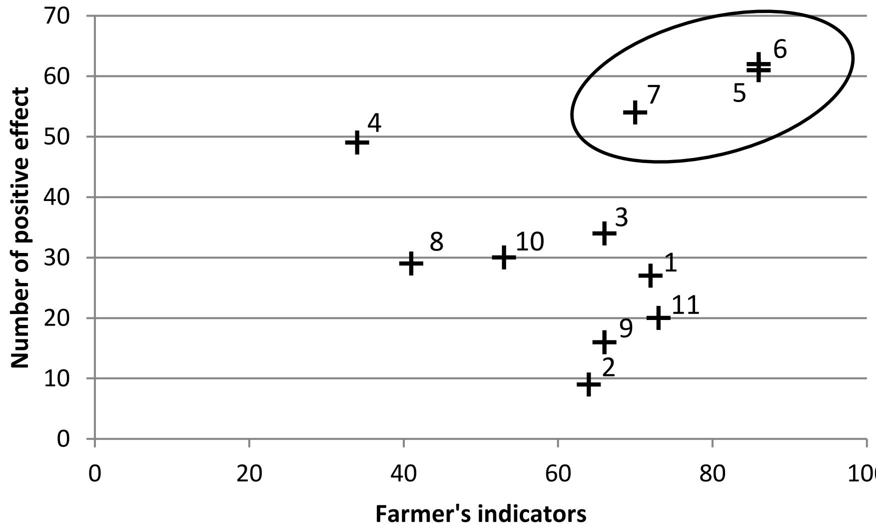


Figure 5. *Number of times the indicators were selected vs. number of times the indicators were sensitive in indicating positive effect*

3.2 WOCAT analysis

Using the standardized WOCAT framework for documentation and evaluation of Sustainable Land Management (SLM) technologies, 1-5 Agricultural Management Practices (AMP) per study site were recorded (with some exceptions of Chinese study sites). The WOCAT framework enabled the study sites to describe the details of land management practices, to show the costs of implementation and maintenance, and to provide a comprehensive list of on- and off-site impacts. In general, one WOCAT technology mostly include one AMP, but out of 31, only 4 documented WOCAT technologies include 2-3 AMPs, such as the technology “Annual green manure with Phacelia tanacetifolia in southern Spain” which contains AMP Nr. 9 “Crop rotation / Control or change of species composition” and AMP Nr. 12 “Integrated pest and disease management incl. organic agriculture.

Most documented WOCAT technologies are related to the AMPs “No-till” (19%), “Manuring & composting” (17%), “Integrated pest and disease management including organic agriculture” and “Min-till” (14% each) while 8 AMPs have not been recorded with WOCAT (see **Figure 6**).

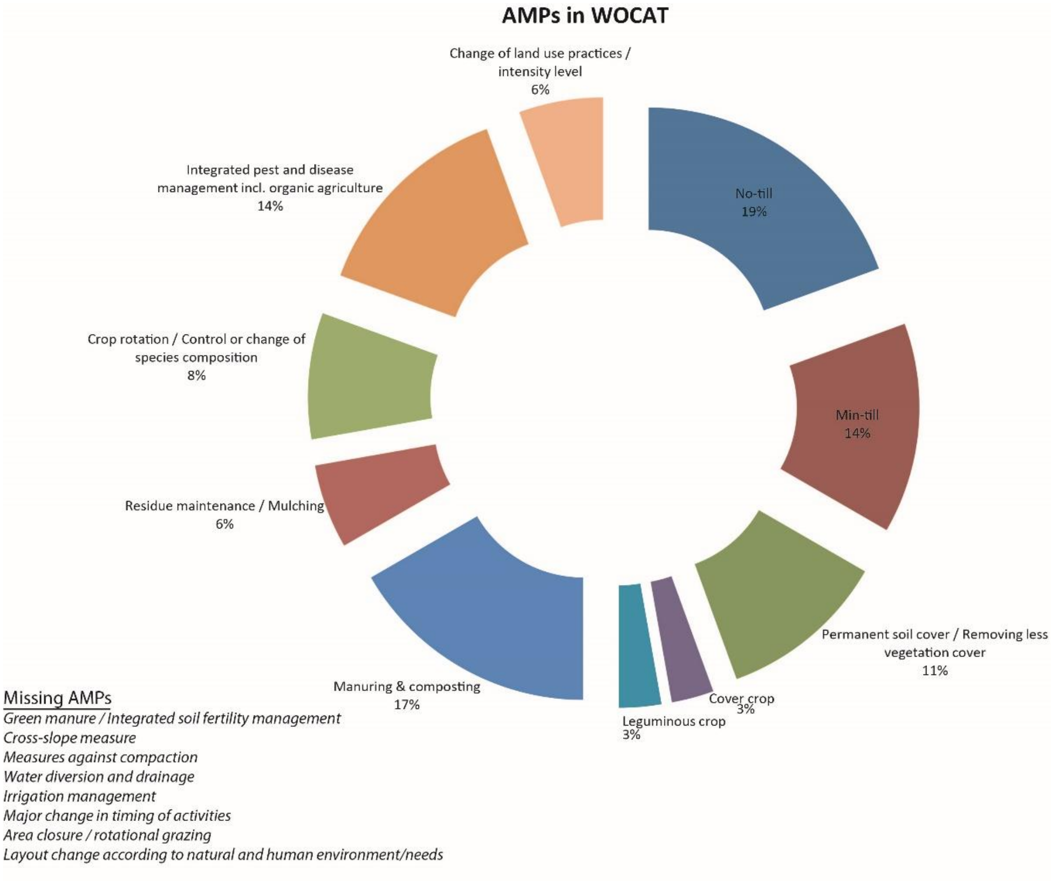


***Figure 6**: Share of AMPs reported with WOCAT*

Looking at the implementation of the new AMPs reported with WOCAT (Figure 7), it can be seen that almost 60% of all technologies where introduced through the innovation of the land users while only roughly one quarter were introduced during the experiment. The main purpose of the reported technologies are to reduce, prevent, or restore land degradation (23%) followed by the motivation to improve production (18%), to create beneficial economic impact (17%) and to preserve or improve biodiversity (16%). Off-site oriented purposes such as reduce risk of disaster (2%) protect watershed and downstream areas (2%) where hardly be mentioned. This is also reflected in Figure 8 where it can be seen that only a few off-site impacts of the AMPs were reported by the study site teams, compared to on-site impacts.

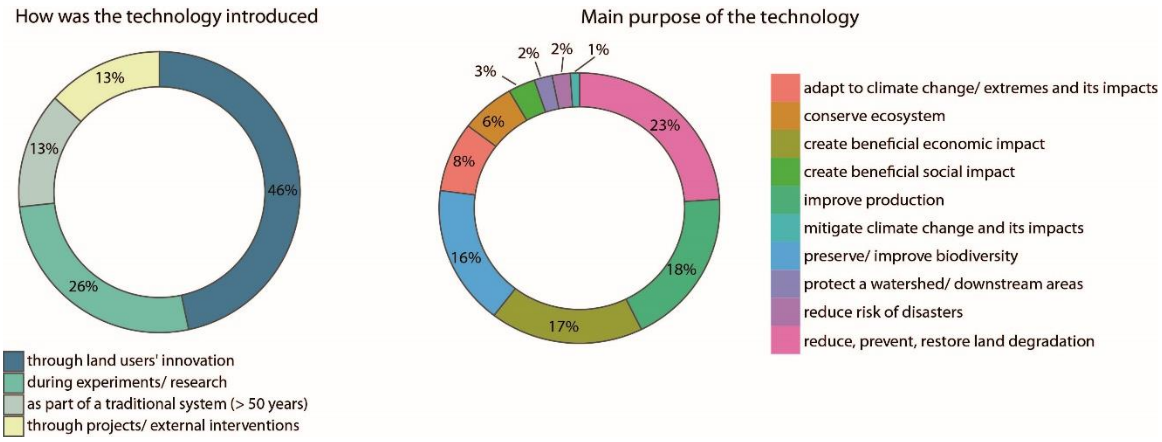


Figure 7*: Way of implementation of the AMPs documented with WOCAT (left) and its main purposes (right)*

An on-site impact is the impact of a new implemented technology in the area or on the plot where the practice is applied. WOCAT differentiates between socio-economic, socio-cultural, and ecological impacts. Over all case studies, it appears clearly that socio-cultural impacts, such as “SLM knowledge” and “food security” have been increases trough the implementation of new practices. In general the new documented technologies also have positive ecological impacts with some exceptions in “soil loss”, “water quality” and “soil compaction”. Most negative impacts are observed or expected in “workload”, “expenses”, and “crop production”, which are all socio-economic impacts and mainly related to the AMP Nr. 12 (integrated pest and disease management incl. organic agriculture). The other most frequently documented AMPs, Nr 1 (no-till), Nr. 2 (min-till) and Nr. 7 (manuring / composting), have all mainly positive socio-economic, socio-cultural, and ecological impacts (see Figure 9).

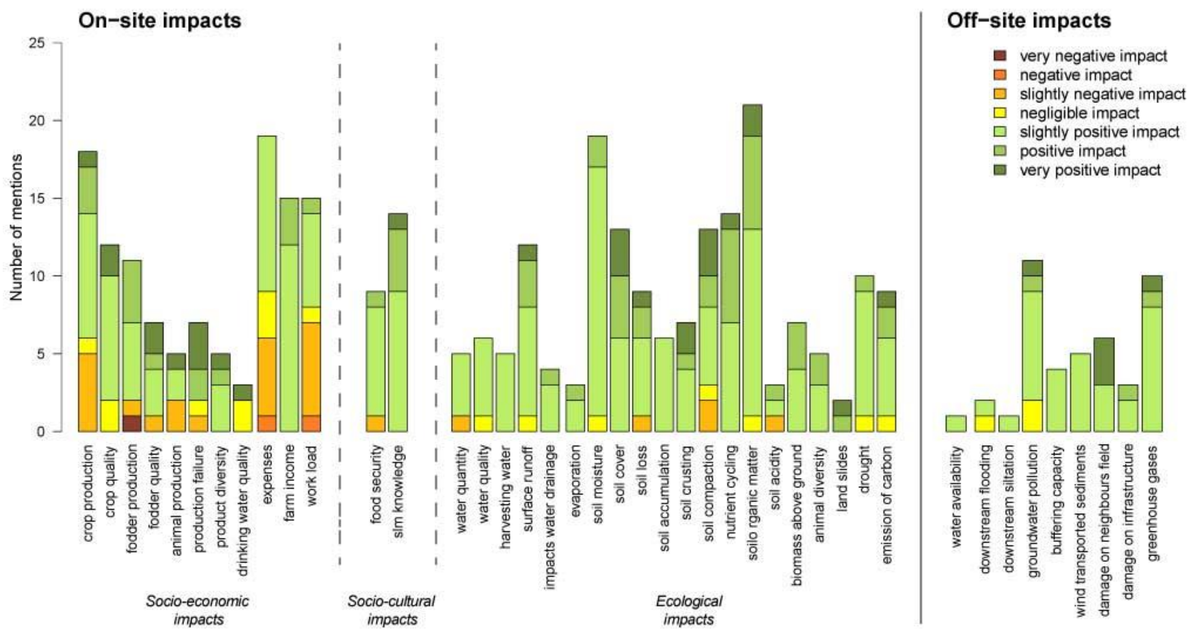


Figure 8*: On- and off- site impacts of the WOCAT technologies*

On the other hand, impacts can also be off-site and affect adjacent areas further downstream with "groundwater pollution" or "damages on infrastructure and fields" (see Figure 8). However, the AMPs implemented recently have all negligible or positive off-site impacts. Especially through reducing "groundwater pollution" and "damages on infrastructure and fields" through reduced surface runoff and soil erosion.

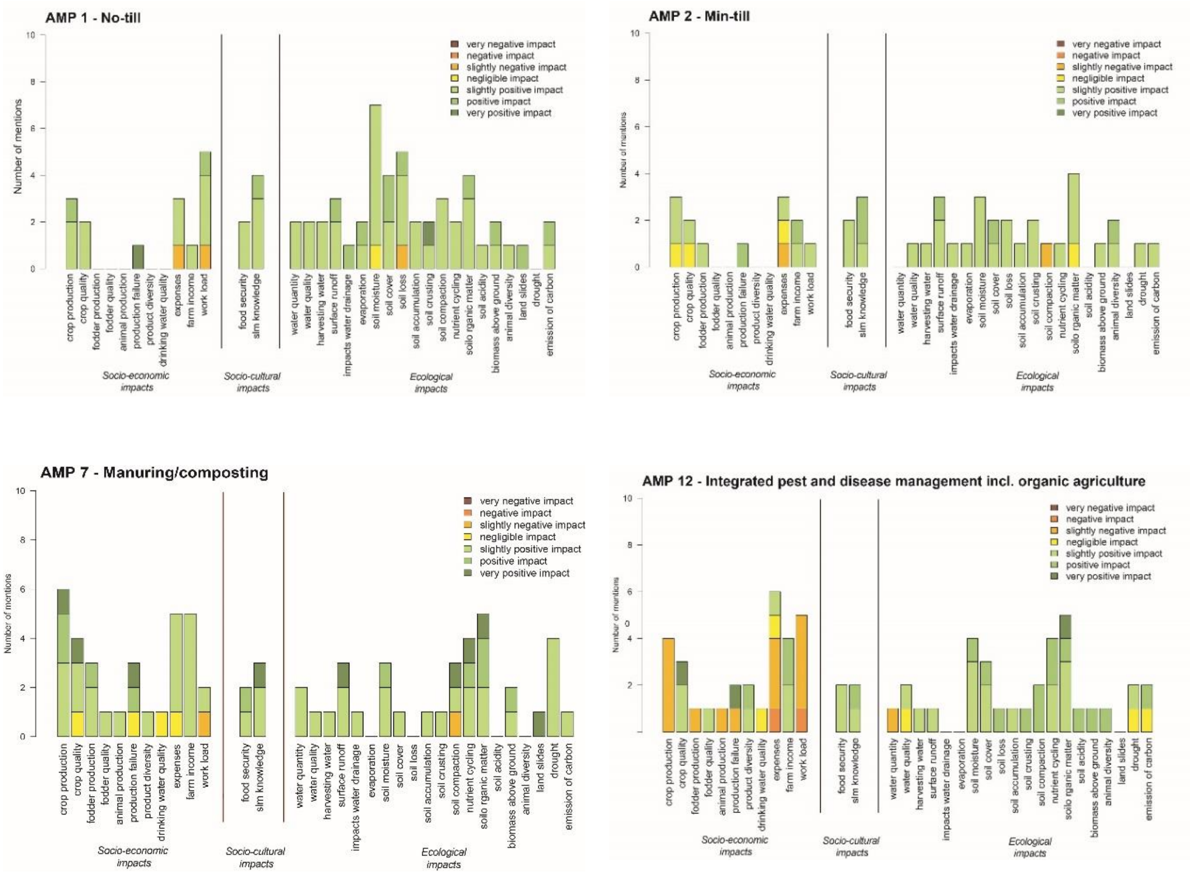


***Figure 9**: Impacts of most frequently documented AMPs on socio-economic, socio-cultural and ecological dimensions*

In summary, the following outcomes can be reported.

- Ten different AMPs have been documented using WOCAT database that are parts of 31 Technologies and 2 Approaches.
- The documented technologies have mainly positive socio-economic, socio-cultural, and ecological impacts with a few exceptions.
- Most negative impacts are observed in "workload", "expenses", and "crop production" and mainly related to the AMP Nr. 12 which is including organic agriculture.
- The study site teams reported few off-site impacts. The off-site impacts are rather negligible or positive with regard to socio-economic, socio-cultural and ecological dimensions.

4. Discussions

The positive impact of the promising AMPs on soil quality was demonstrated in the majority of the CSS under consideration. However, only 71 % of the plots have a single AMP and the remaining ones contain a combination of AMPs. Thus, it is difficult to examine the impact of a single AMP on soil quality but rather the impact of a combination of AMPs on soil quality.

The non-detectable effect of the promising practices on soil quality can be attributed to the type of tillage management, soil type and fertility (Cambisols and Fluvisols) that mask the effect of management practices on soil and also time of the assessment that we have adapted for the current year. For some soils, such as fertile soils, it was difficult to distinguish between the plot with AMPs and the control and the timing of the assessment may be an important parameter influencing the scores of evaluation. Therefore, VSA methodology should be performed in the middle of growing period of a certain crop rotation and/or crop type and repeated several times per year.

In addition, soil threats were only partially covered with our indicators excluding for example nutrient decline. In this study, score of soil quality was done in a qualitative way and will be calibrated against a quantitative approach (WP6). For this purpose, additional evaluation based on laboratory and field measurements that include physical, chemical, and biological aspects are planned in some sites together with the ones proposed here to validate our findings. Plant indicators (e.g., size and development of the root system, crop yield, root diseases, weed infestation) will be considered in the following seasons to check the quality of the information collected by soil indicators with the aim of providing sound data on soil quality and its improvement through promising management practices across Europe and China.

It is worth to mention that the variables describing biodiversity (earthworm numbers) and the infiltration rate provide similar results in the study sites in Europe (**Fig. 2A**). This observation can be explained by the fact that biopores, representing only 0.23–2.00% of the total soil volume, may account for about 74–100% of the total water flux (Alaoui and Helbling, 2006). Their volume reduction due to compaction may significantly reduce vertical infiltration and thus increase surface runoff (e.g., Gerke, 2006; Hendrickx and Flury, 2001). Decreasing infiltration due to soil compaction is due to flow connectivity breaks between the top-few centimetres and the underlying macropores (Jégou et al., 2002). Similar results regarding the variables describing soil structure cannot be drawn for the case of China, probably because of the restricted number of investigated sites, 26 in China against 112 in Europe (**Fig. 2B**) and a wider range of pedo-climatic zones in the former than in the latter.

5 Conclusions and perspectives

On the basis of the literature review, 18 promising agricultural management practices (AMPs) were selected and their impacts on soil quality were evaluated through a Visual Soil Assessment methodology at 14 study sites across Europe and China, covering the major pedo-climatic zones.

Among the 138 sets of paired plots, 75.4 % show a positive impact of innovative AMPs on soil quality, 14.5 % do not show any difference in soil quality between soils under promising practices and soils in the control plots, and the remaining 10.1 % show inverse negative effect on soil quality. In Europe, the most promising AMPs that have been shown to positively impact soil quality are crop rotation / control or change of species composition, manure and composting, minimum tillage and to a certain extent no-till. For China, the most promising AMPs having positively impacted soil quality are residue maintenance/mulching, manure and composting, integrated pest and disease management, and green manure/integrated soil fertility, and irrigation management.

From the 11 variables selected to evaluate soil quality, the ones describing soil structure (porosity, structure and consistency, aggregate stability) revealed to be the most sensitive to soil quality. The variables selected by the farmers for the evaluation of soil quality are also related to soil structure and confirm the consistency of researchers' choice.

Ten different AMPs have been documented using WOCAT database. They are parts of 31 Technologies and 2 Approaches. In general, the documented technologies have mainly positive socio-economic, socio-cultural, and ecological impacts with a few exceptions. Most negative impacts are observed in "workload", "expenses", and "crop production" and mainly related to the AMP Nr. 12 "integrated pest and disease management incl. organic agriculture".

The few off-site impacts reported by the study site teams were negligible or positive with regard to socio-economic, socio-cultural and ecological dimensions.

The indicators selected for soil quality investigation are related to soil structure. We established a new list of indicators to account for soil biological properties based on plant characteristics that includes (crop yield, size and development of the root system, root diseases, weed infestation, soil fauna, and environmental exposure to pesticides). For season 2018 and 2019, the study site teams were requested to use the new list of indicators for soil quality evaluation.

In order to validate our outcomes, quantitative evaluation based on laboratory and field measurements will be carried out during 2018 and 2019 (WP6).

References

Alaoui, A., Helbling, A., 2006. Evaluation of soil compaction using hydrodynamic water content variation: comparison between compacted and non-compacted soil. Geoderma 134, 97–108.

Alaoui, A., Wesseling, J.G., Ritsema, C.J., Schwilch, G. 2018. A new device to assess key soil hydraulic properties. Vadose Zone Journal (in prep.)

Alidad, K., Mehdi, H., Sadegh, A., Hassan, R., Sanaz, B. 2012. Organic resource management: impacts on soil aggregate stability and other soil physico-chemical properties. Agric. Ecosyst. Environ. 148, 22–28.

Ball, B.C., Munkholm, L.J., Batey, T., 2013. Applications of visual soil evaluation. Soil and Tillage Research 127, 1–2.

Blanco-Canqui, H., Lal, R. 2007. Soil structure and organic carbon relationships following 10 years of wheat straw management in no-till. Soil Tillage Res. 95, 240–254

Bossuyt, H., Denef, K., Six, J., Frey, S.D., Merckx, R., Paustian, K. 2001. Influence of microbial populations and residue quality on aggregate stability. Appl. Soil Ecol. 16, 195–208.

Chatterjee, A., 2013. Annual crop residue production and nutrient replacement costs for bioenergy feedstock production in United States. Agron. J. 105, 685–692.

Cookson, W.R., Murphy, D.V, Roper, M.M. 2008. Characterizing the relationships between soil organic matter components and microbial function and composition along a tillage disturbance gradient. Soil Biol. Biochem. 40, 763–777

Dalal, R.C., Allen, D.E., Wang, W.J., Reeves, S., Gibson. I. 2011. Organic carbon and total nitrogen stocks in a Vertisol following 40 years of no-tillage: crop residue retention and nitrogen fertilisation. Soil Till. Res. 112, 133–139.

Dikgwatlhe, S.B., Chen, Z.D., Lal, R., Zhang, H.L., Chen, F. 2014. Changes in soil organic carbon and nitrogen as affected by tillage and residue management under wheatmaize cropping system in the North China Plain. Soil Tillage Res. 144, 110–118.

European Environment Agency, 2006. Corine land cover database passes accuracy test. https://www.eea.europa.eu/highlights/Ann1151398593

Hendrickx, J.M.H., Flury, M., 2001. Uniform and preferential flow mechanisms in the vadose zone. In: Conceptual models of flow and transport in the fractured vadose zone. National Academy Press, Washington D.C, pp. 149–187.

Holland, J.M. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agric. Ecosyst. Environ., 103, 1–25

Hoyle, F.C., Murphy, D.V. 2011. Influence of organic residues and soil incorporation on temporal measures of microbial biomass and plant available nitrogen. Plant Soil 347, 53–64

Hoyle, M.D. Antuono, T. Overheu, D.V. Murphy. 2013. Capacity for increasing soil organic carbon stocks in dryland agricultural systems. Soil Res. 5, 657–667.

Jégou, D., Brunotte, J., Rogasik, H., Capowiez, Y., Diestel, H., Schrader, S., Cluzeau, D., 2002. Impact of soil compaction on earthworm burrow systems using X-ray computed tomography: preliminary study. Eur. J. Soil Biol. 38, 329–336.

Kallenbach, C.M., Frey, S.D., Grandy, A.S., 2016. Direct evidence for microbial-derived soil organic matter formation and its ecophysiological controls. Nat. Commun, p. 13630

Kopittke, P.M., Dalal, R.C., Menzies, N.W. 2016. Sulphur dynamics in sub-tropical soils of Australia as influenced by long-term cultivation. Plant Soil 402, 211–219.

Peigné, J., Vian, J. F., Payet, V., Saby, N. P.A. 2018. Soil fertility after 10 years of conservation tillage in organic farming, Soil and Tillage Research, Volume 175, 2018, Pages 194-204, ISSN 0167-1987, https://doi.org/10.1016/j.still.2017.09.008.

Pelosi, C., Pey, B., Hedde, M., Caro, G., Capowiez, Y., Guernion, M., Peigné, J., Piron, D., Bertrand, M., Cluzeau, D. 2014. Reducing tillage in cultivated fields increases earthworm functional diversity. Appl. Soil Ecol., 83, 79–87.

Li, J., Wen, Y., Li, X., Li, Y., Yang, X., Lin, Z., Song, Z., Cooper, J. M., Zhao, B. 2018. Soil labile organic carbon fractions and soil organic carbon stocks as affected by long-term organic and mineral fertilization regimes in the North China Plain, Soil and Tillage Research, 175, 281–290, ISSN 0167-1987, https://doi.org/10.1016/j.still.2017.08.008.

Liu, C., Lu, M., Cui, J., Li, B., Fang, C. 2014. Effects of straw carbon input on carbon dynamics in agricultural soils: a meta-analysis. Glob. Change Biol. 20 (62), 1366–1381.

Rogger, M., Alaoui, A., Bloeschl, G., et al., 2017. Land-use change impacts on floods –Challenges and opportunities for future research. Water Resour. Res. 53. https://doi.org/10.1002/ 2017WR020723.

Sarker, J. R., Singh, B. P., Dougherty, W. J., Fang, Y., Badgery, W., Hoyle, F. C., Dalal, R. C., Cowie, A. L. 2018. Impact of agricultural management practices on the nutrient supply potential of soil organic matter under long-term farming systems, Soil and Tillage Research 175, 71–81, https://doi.org/10.1016/j.still.2017.08.005.

Shepherd, G. 2000. Visual Soil Assessment. Volume 1. Field guide for cropping and pastoral grazing on flat to rolling country. horizons.mw & Landcare Research, Palmerston North. 84p, ISBN 1-877221-92-9, horizons.mw Report Number 20/EXT/425

Schwilch, G., Bestelmeyer, B., Bunning, S., Critchley, W., Herrick, J., Kellner, K., Liniger, H. p., Nachtergaele, F., Ritsema, C. j., Schuster, B., Tabo, R., van Lynden, G., Winslow, M., 2011. Experiences in monitoring and assessment of sustainable land management. L. Degrad. Dev. 22, 214–225. https://doi.org/10.1002/ldr.1040

Soane, B.D., Ball, B.C., Arvidsson, J., Basch, G., Moreno, F., Roger-Estrade, J. 2012. No-till in northern, western and south-western Europe: a review of problems and opportunities for crop production and the environment. Soil Tillage Res., 118, 66–87

Soon, Y.K., Lupwayi, N.Z. 2012. Straw management in a cold semi-arid region: impact on soil quality and crop productivity. Field Crops Res. 139, 39–46