Promising agricultural management practices and soil threats in Europe and China

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Abstract

Advising farmers on the best agricultural management practices (AMP) to be adopted in order to sustain agricultural productivity while improving soil quality is mandatory to assure future food production. Some promising AMPs have been suggested over the time to prevent soil degradation. These practices have been randomly adopted by farmers but which ones are mostly used by farmers and where they have been applied remains unclear. As part of the iSQAPER project - *Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience*, we: 1) mapped the current distribution of previously selected 18 promising AMPs in several pedo-climatic regions and farming systems along Europe and China, based on ten and four study site areas (SSA), respectively; and 2) identified the soil threats occurring in those areas. In each SSA, farmers using promising AMP's were identified and questionnaires were used to assess farmer's perception on soil threats in their fields. For this study, 138 plots/farms were identified in Europe (112) and China (26). Results show that most widely used promising AMPs in Europe are Crop rotation (15%), Manuring & Composting (15%) and Min-till (14%), whereas in China are Manuring & Composting (18%), Residue maintenance (18%) and Integrated pest and disease management (12%). In Europe, soil erosion is the main threat in agricultural Mediterranean areas, while soil borne pests and diseases are more frequent in the SSAs from France and The Netherlands. In China, soil erosion, SOM decline, compaction and poor soil structure are among the main farmers' concerns. This research provides relevant information for policy makers and the development of strategies to support and promote agricultural management practices with benefits for soil quality.

Keywords: Agriculture . Soil Threats . Sustainability . Promising Management Practices . Study Areas

1. The relevance of promising agricultural management practices (AMP) for soil quality

The growing world population poses a major challenge to global agricultural food and feed production (United Nations 2015). So far, agriculture was able to cope with the increasing demand, but changes in diets food wastage and the challenge of feed more than 9 billion people by 2050 rises the pressure on agriculture sector. Increasing agricultural outputs can be reached either through expansion of agriculture land (FAO 2011) or increasing productivity (Tilman et al. 2011). Both solutions cause an overall set of impacts, such as (a) mining and disruption of nutrient resources, including nitrogen (N) and phosphorus (P) cycles, through increasing use of fertilizers (Gruber and Galloway 2008; Obersteiner et al. 2013), and decrease of soil organic matter (SOM); (b) loss of soil structure (Tiessen et al. 1994; EASAC 2018) and increasing susceptibility to erosion, namely due to high mechanization; (c) decrease in soil biodiversity, though the conversion of natural habitats and loss of endogenous flora and fauna (Chapin et al. 2000; Newbold et al. 2015); (d) decrease of water quality (surface and groundwater), through sediment and nutrients exports by runoff and leachate, as well as consumption of water for irrigation (Scanlon et al. 2007); (e) increase in atmospheric greenhouse-gases, through livestock, consumption of fossil fuels and adoption of management practices that induce greenhouse gas emissions from biological soil processes (Robertson 2000).

Whether in developed or developing regions, such as Europe and China, agricultural intensification based on conventional approaches has resulted in severe soil degradation (Ramankutty and Foley 1999; Lal 2015; EASAC 2018).

This impair the delivery of ecosystem services, comprising more than the provision of food, feed, fibre and fuel, and may lead to failure of agricultural soils. Indeed, soil is currently under several threats that compromise its functions and the potential delivery of ecosystem services. Some examples of soil threats are erosion, soil organic matter (SOM) decline, compaction or biodiversity loss (Stolte et al. 2016). These threats interfere, e.g., on nutrient cycling, water and air circulation, the maintenance of micro and macro fauna. Therefore agricultural management practices that halter ongoing soil degradation, and promote soil quality capable to produce more from less, changing the conventional agricultural paradigm are required (Tilman et al. 2002; Hurni et al. 2015; Wall et al. 2015; EASAC 2018). These promising agricultural management practices are considered here as those maintaining healthy soils, or have been improving the soil quality status markedly (Schwilch et al. 2011).

The focus on the soil as a resource and the need to use it in a sustainable way was patent in the Soil Thematic Strategy developed by the European Commission in 2012. The four pillars of the Strategy, namely awareness raising, research, integration, and legislation, intend to preserve the soil functions while also restore already degraded soils. Therefore the consolidation of harmonized soil monitoring and soil quality indicators is necessary to better compare the soil performance along different countries (European Commission 2012). Integrated in this context, the H2020 iSQAPER research project – *Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience* – aims to develop a Soil Quality app (SQAPP) to link agricultural management practices (AMP) to soil quality indicators. This easy-friendly tool will provide a direct and convenient way to advise farmers and other stakeholders regarding the best management practices to be adopted in specific conditions to improve soil quality.

Soil quality is a difficult concept to establish, and several indicators/parameters have been considered by different authors during the last decades (Bünemann et al. 2018). Thus, iSQAPER project includes the development of a soil quality index to be used by the app. However, there is also an urgent need to link the impact of different agricultural management practices to soil quality impacts, in order to ensure both soil protection and the sustainability of the agriculture sector. Some promising management practices have been suggested and adopted to prevent soil loss, decreasing organic matter or soil salinization all over the world. These practices, including no-tillage, cover crops or soil cover, have been randomly adopted by farmers once they are faced with soil degradation problems in their fields. However, which practices are already in used by farmers and where are they mostly adopted remains unclear. This information is important for policy makers, farmer's management advisers and scientists actively engaged in developing and promoting agricultural management practices to correctly address the local soil problems.

iSQAPER project has 25 partners, of which 14 are participating as study site areas, with long time agriculture research, located in a variety of climatic areas from Europe and China. This study, developed under iSQAPER project, aims to (i) map the distribution of promising AMPs (pre-selected from a list developed by the WOCAT consortium) along the study site areas of Europe and China; and ii) identify the most severe soil threats in each study site area. Europe and China were selected for this assessment due to the agriculture intensification experienced in the last 50 years, and, thus, the farmers' need to adopt new practices to overcome the current soil degradation problems. This assessment will provide an overview on the most promising practices already in use to address specific soil threats and the farmers' perception of the most important problems compromising soil quality in their fields. By doing this, this study brings together knowledge about the adoption of AMPs, which is currently dispersed, while also accounting farmers awareness of the on-going threats.

2. Study site areas in Europe and China – location and characterization

The studied sites areas (SSA) considered in this study are distributed in Europe (6) and China (4) (**Fig. 1**) and consist in large agricultural research areas (ranging from 8 to 8000 km^2), under research for more than 4 years. This long term investigation assures (i) adequate description of geomorphologic, hydrologic and climatic conditions; (ii) documentation of typical agricultural management activities; and (iii) frequent soil monitoring activities to assess the impact of management activities and innovation actions on soil quality, and involve relevant stakeholders in the agriculture paradigm. In Europe, the 10 study areas covered 6 out of the 8 climatic zones (Tóth et al. 2013): Boreal to sub-Boreal, Northern sub-Continental, Southern Sub-Continental, Atlantic, Mediterranean Temperate and Mediterranean semi-arid. In China, climate variability is higher than in Europe, and only 3 out of 10 climatic areas (Wu et al. 2010) were investigated: Central Tropical Asia, Warm Temperate and Middle Temperate zone (Barão et al. 2019).

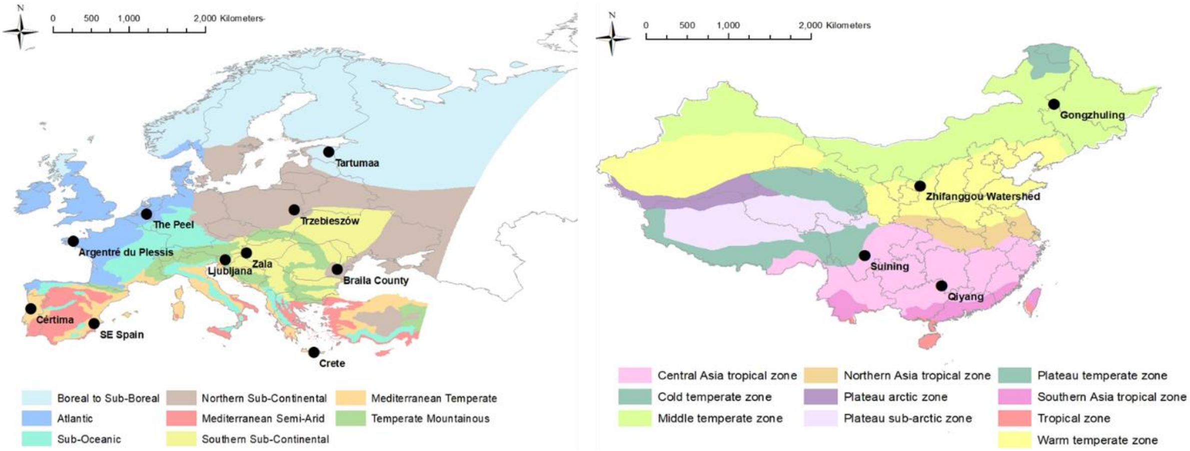

Fig. 1 Location of the Study Site Areas (SSA) in Europe (left) and China (right), within the climatic zones.

The most common soil types within each climatic region were also identified (**Fig. 2**). Cambisols are the main soils occurring in Sub-oceanic, Mediterranean both semi-arid and temperate, Temperate mountainous and Atlantic climatic regions. In Boreal to sub-boreal area, the most occurring soil type is the Podzol, while in Northern and Southern Sub-continental regions a variety of soil types, including Chernozems, Albeluvisols, Phaozems, Luvisols and Cambisols, were recorded. Acrisols, Umbrisols, Cryosols and Andosols soil types are almost absent from these regions.

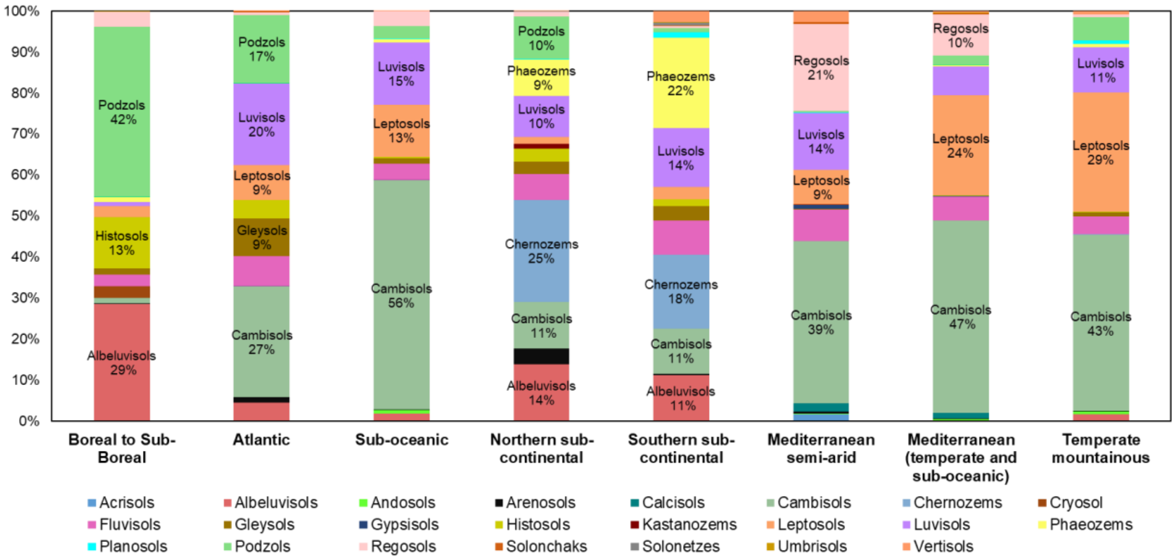

Fig. 2 Main occurring soil types in each climatic region within Europe

The characterization of each SSA included also the identification of the most significant farming systems, based on national databases. The farming systems classification used in this study was adapted from CORINE land cover assessment (European Environment Agency 1994). It considers three classifications: Arable Land, Permanent Crops, and Pastures, each one with different sub-classes, as presented in **Table 1**.

Table 1 - Farming systems classification, based on CORINE land cover, used during the identification of farms/plots with promising AMPs in the study site areas

CODE	Farming system	CODE	Farming system
1.	Arable Land	1.2.3	Legumes
1.1	Non-irrigated Arable Land	1.2.4	Oil crops
1.1.1	Cereals	1.2.5	Fodder crops
1.1.2	Maize	1.2.6	Root crop
1.1.3	Legumes	1.2.7	Follow
1.1.4	Oil crops	1.2.8	Flowers, fruits and vegetables
1.1.5	Fodder crops	2.	Permanent
1.1.6	Root crop	2.1	Vineyards
1.1.7	Follow	2.2	Fruit trees and berry plantation
1.1.8	Flowers, fruits and vegetables	2.3	Oil groves
1.2	Permanently irrigated Arable Land	3.	Pastures
1.2.1	Cereals	3.1	Extensive
1.2.2	Maize	3.2	Intensive

3. Promising Agricultural Management Practices (AMPs)

The promising AMPs considered in this work were based on a preliminary list from a literature review and a categorization list of Sustainable Land Management practices (Schwilch et al. 2011), developed by the WOCAT consortium (www.wocat.net). This list of AMPs was grouped into 5 classes of agriculture management practices, focused on: 1) soil; 2) nutrient; 3) pest; 4) water and 5) crop and land use change (**Table 2**).

AMPs strategies include the adoption of practices such as no-tillage and minimum tillage, which aim to diminish soil disturbance to avoid soil loss and the decrease of fertility. Other practices include cover crops, where a second crop is grown to maintain the soil continuously covered, while also improving the productivity. This is also the target of permanent soil cover and residue maintenance practices, where different strategies are used by farmers to avoid bare soils during the agricultural seasons. Other soil management practices include activities to decrease soil compaction, which is often a problem in agriculture fields due to heavy machinery, cattle movement and the high clay content of the soil.

Nutrient management practices adopted by farmers aims to maintain adequate levels of organic matter and different macro and micro nutrients in the soil. It includes the application of, e.g., manuring and composting, by spreading on the field different organic materials or green manure, where the material returning to the soil is a crop grown specifically for that end. Growing leguminous crops, especially in crop rotation practices, has the advantage of benefiting from the nitrogen fixator symbioses between leguminous plants and some fixator microorganisms. Crop rotation together with organic agriculture are also practices adopted by farmers to avoid yield losses due to diseases, by maintaining crops without disruptions and reducing the ability of invasion species to use common resources.

Irrigation management and water drainage are management practices devoted to increase water efficiency uptake by plants, either by lowering evaporation or by reducing drainage, and to prevent damages caused by floods and storms.

Other adopted practices by farmers in the SSAs have a broader frame, targeting globally the crop management. It includes changing the agricultural activities timing to increase yield production and resource uptake efficiency by adapting vegetation growth dynamics to climatic variations. Other practices include changing the layout according to natural and human environmental needs, changing the land use practices and also the use of rotational grazing (Barão et al. 2019). These practices aim to adequate agricultural fields and production to local conditions, enhancing the ability of the ecosystem to recover from anthropogenic impacts and/or ecosystems resilience to climate changes (**Fig. 3**).

Table 2 - List of promising AMPs in SSAs with description and expected impacts/ecological benefits

AMP class	AMP list	AMP description	Expected impacts / Ecological benefits
Soil Management	***1*** *- No-till*	A system where crops are planted into the soil without primary tillage	- Reduces decomposition rates of OM leading to increasing levels in the soil, enhances cycling of nutrients, enhances soil structure and increases water infiltration. - Improves soil biological diversity including disease and weed suppression.
	2 *- Min-till*	Tillage operation with: a) reduced tillage depth; b) strip tillage; c) mulch tillage; 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 diversity including disease and weed suppression.
	3 *- Permanent soil cover / Removing less vegetation cover*	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 and less prolonged crop water stress, and increases availability of plant nutrients. - Provides source of food and habitat for diverse soil life: creates 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. - Increases soil regeneration. - Mitigates temperature variations in the soil surface and profile. - Improves the conditions for the development of roots and seedling growth.
	4 *- Cover crops*	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*	Maintaining crop 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 shelter for wildlife.
	6 *- Cross-slope measures*	Structural measures along the contour to break slope lengths, such as terraces, bunds, grass strip, trashlines, contour tillage	Reduces surface runoff and erosion (increases infiltration capacity).
	7 *- Measures against compaction*	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 under rotation systems, such as: annual alfalfa, beet, sunflower, okra, flax, turnip. c) Controlled traffic farming: 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 soil layers 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)
Nutrient Managem ent	***8*** *- Leguminous crops*	A leguminous crop is a plant from the Fabaceae family (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 nitrogen to the soil, reducing chemical fertilizers requirements. (See also cover crop and green manure)

AMP class	AMP list	AMP description	Expected impacts / Ecological benefits
	9 *- Green manure / Integrated soil fertility management*	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 in 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]*	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.
Pest Management	***11*** *- Crop rotation[a] / Control or change of species composition[b]*	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*	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.
Water management	***13*** *- Water diversion and drainage*	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*	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
Crop management and land use change	***15*** *- Major change in timing of activities*	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*	e.g. 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*	Complete or temporal stop of use to support restoration	- Improves vegetative cover, reduces intensity of use, and soil compaction and erosion.
	18 *- Change of land use practices / intensity level*	e.g. 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.

Fig. 3 Examples of promising AMPs implemented: minimum tillage in SSA in Greece (top left), no-tillage in SSA in Estonia (top right), organic agriculture in SSA in Poland (bottom left) and contour tillage in SSA in Hungary (bottom right).

4. Selection of plots/farms in SSAs where AMPs are implemented and main soil threats identification

Interviews to local farmers took place in each SSAs, to further identify farms/plots where promising AMPs were being adopted. The selection of these representative farms/plots followed the subsequent criteria:

- Plots/farms should include 3 different promising AMPs in 2 different farming systems and 2 different soil types – a total of 12 plots/farms per SSA;
- The promising AMPs considered should be part of **Table 2**;
- Plots/farms should be representative of the most occurring farming systems in the region (**Table 1**);
- Plots/farms should occur in representative soil types within the region (**Fig. 2**);
- In case of multiple possible choices, selection favoured the most representative soil type of the SSA;
- Within the same climatic region, selection favoured the variation of promising AMPs.

In order to identify the most relevant soil threats affecting the SSA, each Case Study Site project partner ranked the mains soil threats. The soil threats considered were:

- Erosion;
- Soil organic matter (SOM) decline;
- Nitrogen leaching;
- Soil-borne pests and diseases;
- Compaction;
- Poor water holding capacity;
- Salinization;
- Poor structure.

The list was produced by the experienced researchers working on sustainable agriculture in the SSA (and research team from iSQAPER project), after informal interviews with the farmers (total of 98) about the plots and soil threats where the AMPs were identified. After this, each research team responsible for individual SSA translated their general perception of soil threats into a rank from 1 to 8 (the number of soil threats considered), where 1 represents the most severe and 8 the least severe soil threat. This rank is therefore a result from each research team conclusions, based on farmers reality identified during the selection of plots.

5. Promising AMPs implemented along the SSAs

The intended variability in the identification of plots/farms per SSA considering different farming systems and soil types, was not always possible along the climatic regions. Thus, a total of 138 plots/ farms with promising AMP's were identified (112 in Europe and 26 in China) along the different SSAs and included in this study. The number of plots/farms with promising AMPs identified in the SSAs (**Fig. 4**) were mostly from Arable land farming systems (63% in Europe and 92% in China), followed by Permanent crops (23% in Europe and 4% in China) and Pastures (14% in Europe and 4% in China).

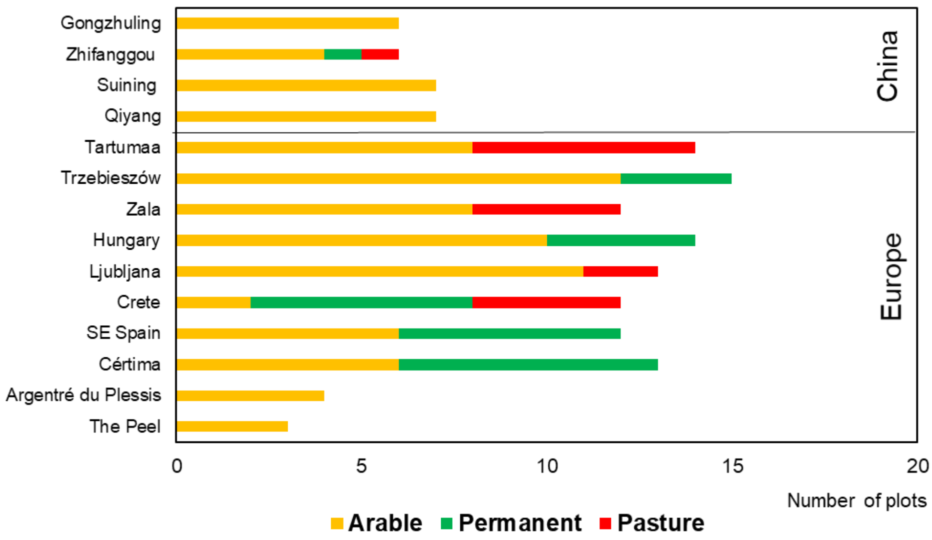

Fig. 4 Farming systems' frequency distribution in the identified farms/plots with promising AMPs per SSAs.

As for the soil types of the identified farms/plots in Europe, the majority were located in Cambisols (29%), Fluvisols (17%) and Luvisols (15%), while in China, Anthrosols were the most representative within the farms/plots identified (27%), followed by Cacilsols (23%) and Regosols (15%) (**Fig. 5**).

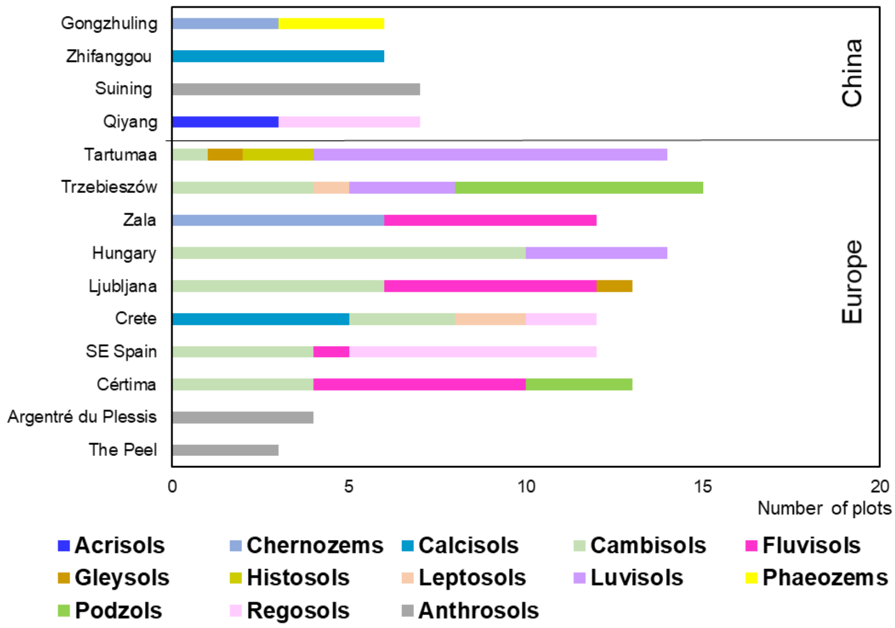

Fig. 5 Frequency distribution of soil types in the identified farms/plots with promising AMPs within the SSAs

The most common promising AMPs in the identified plot/farms within Europe were Crop rotation (15%), Manuring & Composting (15%) and Min-till (14%), while in China were Manuring & Composting (18%), Residue maintenance (18%) and Integrated pest management and diseases (12%) (**Fig. 6**). However, it is important to refer that while some of the plots/farms identified only one promising AMP being used by the farmer (71%), in some other SSAs farmers use a combination of different AMP's at the same time (29%).

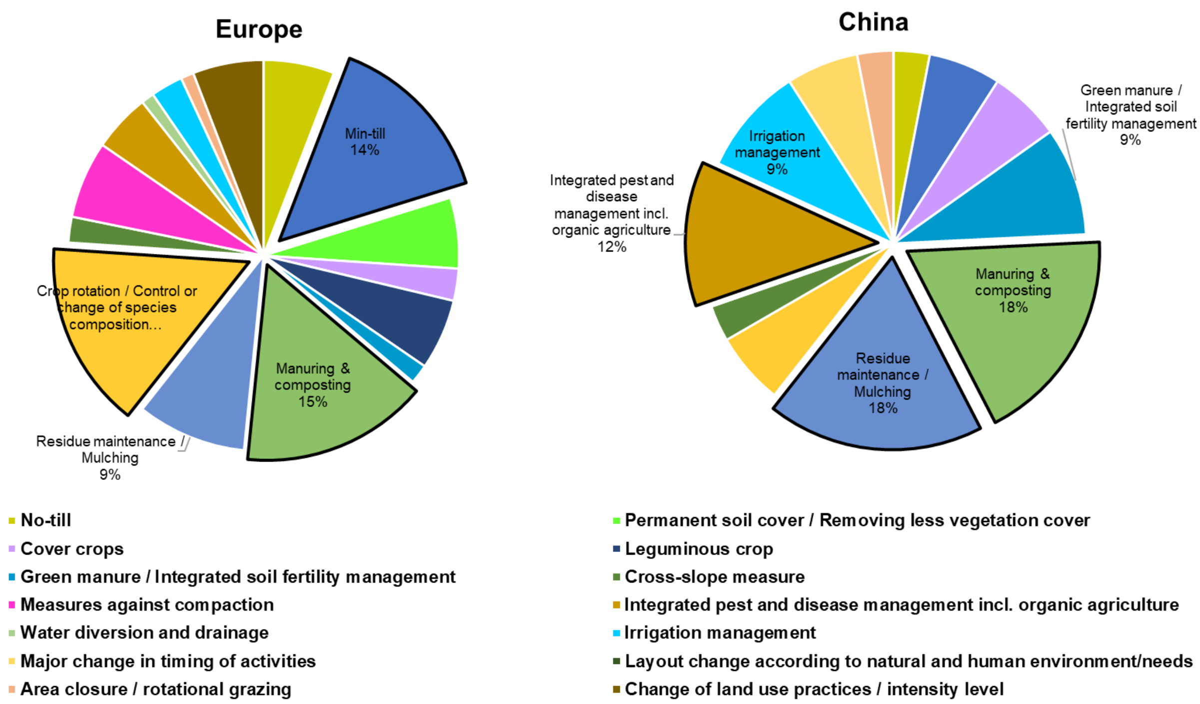

Fig. 6 Promising AMPs identified in plots/farms from Europe (left) and China (right)

Min-till was mainly identified in Portugal, Spain, Hungary and Estonia, crop rotation was mainly used in Hungary, Spain, Poland and Estonia, while Manuring & Composting was adopted mainly in Spain, Hungary, Poland, Estonia and also China. Some of the promising AMPs were less represented within the SSAs, being applied in one or two SSAs. It is the case of *Area closure /rotation grazing* only present in Romania and Zhifanggou, China, *Major change in timing of activities*, only identified in Qiyang, China (**Fig. 7**).

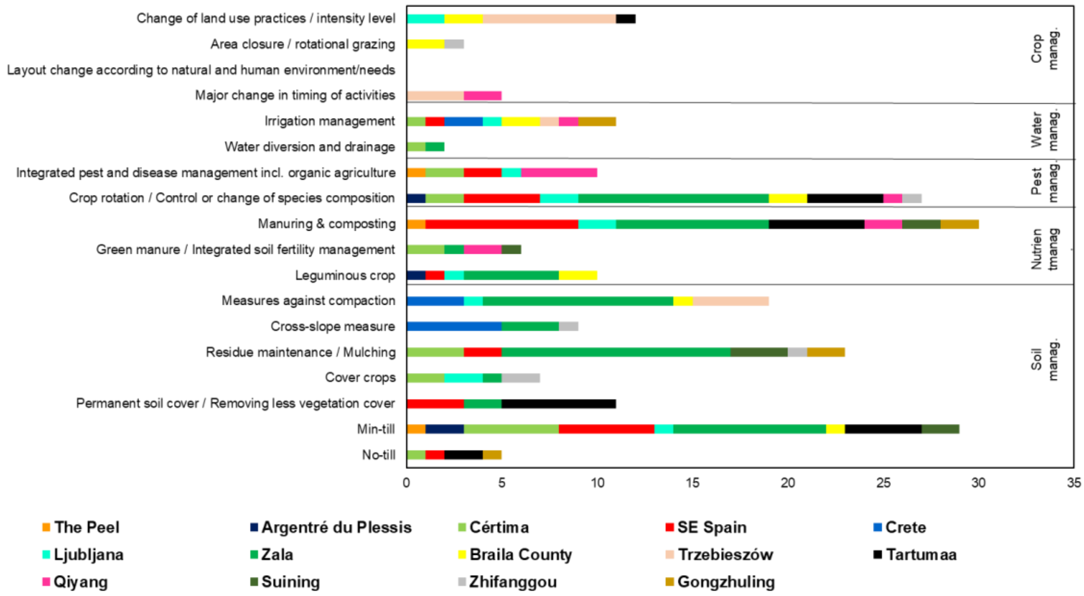

Fig. 7 Promising AMPs adopted by farmers in the identified farms/plots in each SSA (Europe and China)

In Europe, the majority of promising AMPs identified in plots/farms selected per SSAs were linked to soil management (40% - 55%), except in the Northern Sub-continental zone (12%). The class of nutrient management AMPs was also consistently the second most identified in all climatic areas of Europe (14%–33%), except for the same Northern Sub-continental where it was dominant (35%). The pest management AMPs is the third most identified (14–29%) in Europe, while water management AMPs were only identified in the Mediterranean temperate, Northern and Southern Sub-Continental zones. The crop management AMPs were identified in these three climatic regions and also in the Boreal to Sub-Boreal zones, but always in small percentages (2%–12%) (**Fig. 8**).

In China, however, the distribution of identified AMPs among the climatic regions was more variable. The Cold semi-arid climatic zone was the only area exhibiting a similar trend observed in Europe, with the vast majority of AMPs linked to soil management practices (67%). However, nutrient management AMPs were absent from this case study area, while pest management and crop management share the same representativeness (17%) in the other Chinese countries. In Central tropical Asia region, the most present AMPs were instead the ones related to nutrient management (35%), although every other class was represented. Finally, with a completely different trend, the AMPs identified in the region of Middle Temperate zone were predominantly linked to soil management (43%), followed by nutrient management (29%) and water management (29%) (**Fig. 8**).

In the SSAs, both European and Chinese farmers use promising AMPs from the soil management category, followed by nutrient and pest management. However, in Europe this tendency is recorded in all climatic areas in the same proportion. It is also clear that water management practices are not so much adopted by European farmers (4 - 7%), although its absence in regions such as the Mediterranean Semi-arid is due to the limitation of plots/farms identified within this climatic region.

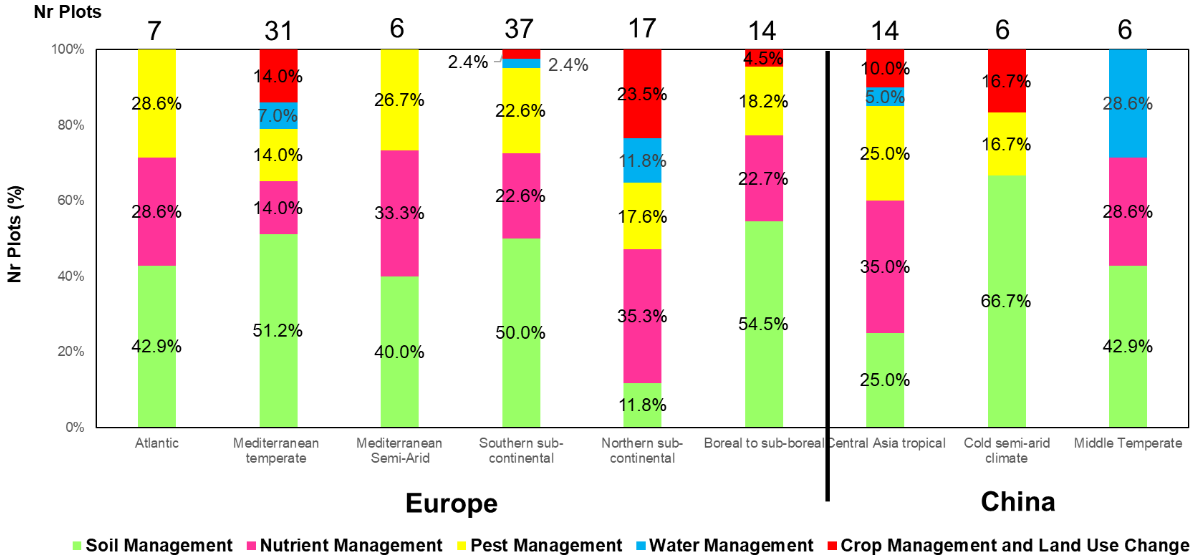

Fig. 8 Representativeness of promising AMPs distribution categories in Europe and China grouped by climatic region.

6. Soil threats in the SSAs from Europe and China

In the Atlantic region, main soil threats are nitrogen leaching, soil-borne pests and diseases and compaction. In the Mediterranean temperate zone the main problems are erosion, SOM decline, compaction, poor structure and salinization. In the Southern sub-continental region, however, the main soil threats identified are nitrogen leaching and poor water holding capacity, as well as erosion and SOM decline. In the Northern sub-continental region the main threats focus on poor water holding capacity, poor structure, compaction, SOM decline and salinization. Finally, the Boreal to Sub-Boreal region reported problems with SOM decline, compaction and poor soil structure.

In China, a wider variety of soil threats was recorded (**Fig. 9**). The results show that in the region of Central Asia Tropical, the two SSAs registered problems mainly concerning erosion, SOM decline and poor soil structure. Additionally, Qiyang also shows problems with compaction and soil-borne pests and diseases, while Suining shows problems with poor water holding capacity. The Warm temperate region, represented by Zhifanggou study site shows also a high incidence of erosion problems, SOM decline and poor soil structure, while the Middle temperate zone, represented by Gongzhuling is more affected by SOM decline (Barão et al. 2019).

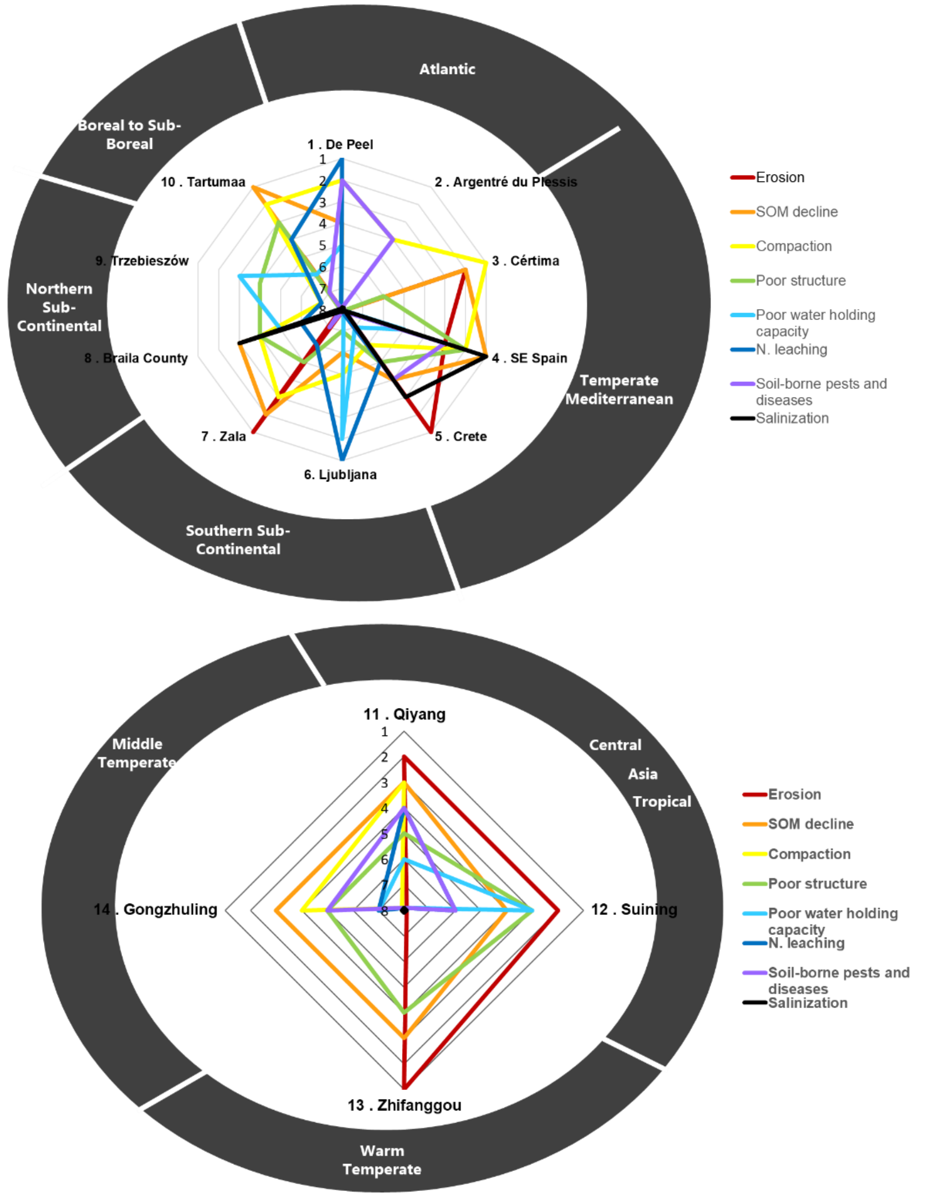

Fig. 9 Soil threats severity grouped by climatic zone in Europe (left) and China (right), ranked from 1 (highest) to 8 (lowest). SE Spain includes plots located in the region of Valencia, Alicante and Murcia. The highest severity scores (1, 2 and 3) are highlighted in bold.

7. Soil threats and management practices in Europe and China

Results from this study refer to a previously summarized list of promising AMPs (Table 1) identified along specific SSAs and may not be representative to other areas of Europe and China. However, the perception of the interviewed farmers and researchers in the SSAs regarding to soil threats are generally in line with the distribution of the soil threats along Europe, reported in previous studies (Tóth et al. 2008; Panagos et al. 2015b; Orgiazzi et al. 2016). However, while some of the threats seem to concentrate in specific regions, others are reported as severe or moderate in almost all of the SSAs. Furthermore, since these SSAs are relevant areas for land management and are object of research for quite some time, the study of selected promising AMPs being used in plots/farms are an important referential to understand farmers choices for using certain management practices. Farmer's choices revealed particular interest in adopting promising AMPs concerning soil and nutrient management practices (**Fig. 8**). This concern was transversal from Europe to China, although different promising AMPs where reported locally.

In Europe, the most identified promising AMPs denoted farmer's preoccupation with soil organic matter losses and soil erosion and focuses on soil protection, such as evidenced by the large adoption of minimum tillage practices (López-Bellido et al. 1997; Hernanz et al. 2002). Also, the high implementation of manuring & composting reinforces the farmers' need to increase soil organic levels in Europe and the focus on recycling secondary products from farms into a greener management approach (Damodar Reddy et al. 2000). The high number of farmers using crop rotation techniques denotes preoccupation with soil protection (Blackshaw et al. 2001) and the recognition that, in order to have high yields, it is necessary to have a healthy soil with multiple nutrients (De Varennes et al. 2007). In fact, growing crops in rotation systems, opposing to mono-cultures, ensures nutrient recycling within soil and sustains the micro and macrofauna, which are determinant to assure healthier crops with greater resistance to diseases (López-Fando and Bello 1995; Tiemann et al. 2015). In China, residue maintenance by farmers is another management practice that highlights farmers need to protect the soil against erosion, while also using the residues to feed the soil with organic matter and nutrients. Soil loss and SOM decrease are serious problems affecting both Europe and China, due to the intense agricultural activities. The fact that soil is being lost faster than it can be replaced (Panagos et al. 2015a) and that organic matter is decreasing (Lugato et al. 2016) affects soil quality and consequently the arable soil capacity to produce the expected crops yields. Organic matter provides a source of nutrients to the soil and sustains the food web for the micro fauna, while also promoting water retention (Allison 1973).

This means that despite the variability (i.e. pedoclimatic, topographic, political, social-economic) between the two continents, there seems to be a common adopted strategy by local farmers, who see beneficial effects in using these promising practices in the short term and are careful enough to adopt management practices with the goal of maximizing benefits on the medium-longer term. This convergence is also present in the SSAs from different European countries, although different versions of the RDP (Rural Development Programme) were adopted locally.

The highlighted concern of famers with soil protection against erosion and the loss of organic matter discussed before is therefore blurred by the fact that other threats such as salinization, nitrogen leaching or poor water holding capacity, are identified without proper management practices. It is important to consider the role of physical soil properties (e.g. texture and pH) or geographical constrains (e.g. slope) on the type of soil threat occurring in different regions. Climatic variability within the SSAs is also responsible for the occurrence of certain threats in specific places such as salinization. Furthermore, these parameters influence the site-specific type of management practices adopted by farmers to overcome the situation.

The information provided in this study should be used as a basis for future decisions concerning the support of different AMPs to prevent soil degradation and to enhance soil quality. Policymakers should be aware that ongoing threats are menacing soil quality, and therefore agricultural productivity along Europe and China and the current adoption of AMPs to deal with soil threats is not properly implemented. However, this study also shows the growing awareness and concern that farmers have towards erosion and soil organic matter loss, which can be even more supported by policy strategies in the future. The farmers concern with these issues shows clearly that soil quality and productivity are been compromised.

Additionally, results can also be used to promote and support the management practices which can ameliorate soil threats that are not successfully addressed. These AMPs should be site specific since they target soils threated by salinization and nitrogen leaching which are very much influenced by pedoclimatic variations.

8. Conclusions

The present study identified the currently used promising AMPs by farmers from 14 SSAs in Europe and China, along different climatic regions.

The main conclusions are:

- The most adopted promising AMPs in the SSAs are focused on: a) soil management, b) nutrient management, and c) pest management. Promising AMPs concerning water and crop management & land use were less common in the investigated study areas.
- Soil threats such as erosion and SOM decline were listed as the most severe in SSAs from the same climatic regions, namely in the Mediterranean, while others such as soil compaction were present in all SSAs. The study highlights the concern of farmers with soil protection and soil organic matter loss, through the adoption of specific AMPs that intend to decrease the annual soil loss and promote the accumulation of soil organic matter. These practices should be supported in the future and more

attention should be given to other AMPs that actively target damages from other soil threats such as salinization and nitrogen leaching.

- Information on main soil threats and AMPs easily accepted and implemented by farmers should be considered in future policy strategies, either to support farmers already adopting promising AMPs to promote soil quality and to establish priorities for future incentives.

Future research should provide special attention to the analysis of the impacts of the selected AMPs on soil quality in the selected plots/farms, in order to better understand the effectiveness of the AMPs in addressing soil threats.

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