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Assessment of promising agricultural management practices

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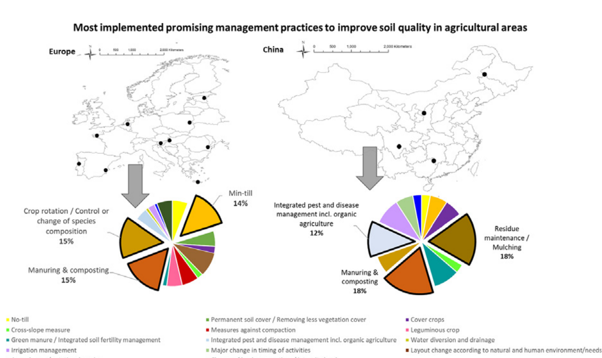
HIGHLIGHTS

- Promising agricultural management practices (AMP) adopted by farmers improve soil quality.
- iSQAPER project aims to develop an app to advise farmers on selecting the best AMPs.
- Some of the most promising AMP was Crop rotation and Manuring & Composting.

GRAPHICAL ABSTRACT



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ABSTRACT

iSQAPER project - *Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience* - aims to develop an app to advise farmers on selecting the best Agriculture Management Practice (AMPs) to improve soil quality. For this purpose, a soil quality index has to be developed to account for the changes in soil quality as impacted by the implementation of the AMPs. Some promising AMPs have been suggested over the time to prevent soil degradation. These practices have been randomly adopted by farmers but which practices are most used by farmers and where they are mostly adopted remains unclear.

This study is part of the iSQAPER project with the specific aims: 1) map the current distribution of previously selected 18 promising AMPs in several pedo-climatic regions and farming systems located in ten and four study site areas (SSA) along Europe and China, respectively; and 2) identify 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 significance in the area.

138 plots/farms using 18 promising AMPs, were identified in Europe (112) and China (26).Results show that promising AMPs used 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 is more frequent in the SSAs from France and The Netherlands. In China, soil erosion, SOM decline, compaction and poor soil structure are among the most significant. This work provides important information for policy makers and the development of strategies to support and promote agricultural management practices with benefits for soil quality.

1. Introduction

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 more land area dedicated to agriculture (FAO, 2011) or through productivity increases (Tilman et al., 2011). Both solutions cause an overall set of impacts such as: a) mining and disruption of nutrient resources, such as the 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) 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 fresh and groundwater 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 (Lal, 2015; Ramankutty and Foley, 1999) and the consequent failure of agricultural soils to deliver the more than ever required ecosystem services, comprising more than the provision of food, feed, fibre and fuel. Indeed, soil is currently under several threats that compromise its functions and the ecosystem services potential. Some examples of threats affecting soil are erosion, soil organic matter (SOM) decline, compaction or biodiversity loss (Stolte et al., 2016). These threats interfere and compromise the organic matter level in soil, the water and air circulation, the diversity of micro and macro fauna among others. Therefore agricultural management practices that halter ongoing soil degradation, promote sustainable land management capable to produce more from less, and to change the conventional agricultural paradigm are required (Hurni et al., 2015; Tilman et al., 2002; Wall et al., 2015). 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 the 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, the decrease of 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, located in a variety of pedoclimatic areas from Europe and China, and object of agriculture research for long time. This study, developed under iSQAPER project, aims to (i) map the distribution of promising AMP's (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 the farmers' need to adopt new practices to overcome the current problems driven by intensive agriculture practices. This assessment will provide an overview on the best promising practices already in use and their link to soil threats as an attempt to address soil quality improvement in future strategies.

2. Material and methods

In order to understand which promising management practices have been adopted by farmers in Europe and China, 14 study site areas (SSA) were considered located in different pedoclimatic regions and used in different farming systems. For each SSA, farmers using promising agricultural practices (AMP's) were identified through the process described below.

2.1. Study site areas (SSA)

The SSA include 10 sites located in Europe and 4 sites in China (Fig. 1). These SSAs consist in large agricultural research areas (ranging from 8 to 8000 km^2). This long term investigation assures (i) adequate description of geomorphologic, hydrological and climatic conditions; (ii) documented and studied typical agricultural management activities; and (iii) frequent soil monitoring activities, as well as research activities such as testing of management activities and innovation actions which are relevant to improve soil quality, and involve important local 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, but only 3 out of 10 climatic areas (Wu et al., 2010) were investigated: Central Tropical Asia, Warm Temperate and Middle Temperate zone (Fig. 1).

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* (including non-irrigated and permanently irrigated arable lands, growing cereals, legumes, oil crops, fodder crops, root crops, flowers, fruits and vegetables and also fallow); *Permanent Crops* (including vineyards, fruit trees and berry plantations and oil groves) and; *Pastures* (comprising extensive and intensive pastures).

In a first step, there was an identification of the most widely used farming system in each SSA, using national databases. Based on this preliminary survey, interviews to local farmers in the SSAs took place to further identify farms, from the most representative local farming systems, where promising AMP's were being used. These inquires included the identification of all farmers and their farms/plots within the SSA and the listing of: 1) farming systems used; 2) soil type and 3) the type of management performed in the land.

The promising AMP's considered for this identification 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). The preselected 18 promising AMP's identified along the pedoclimatic and farming systems gradients of the SSAs are shown in Table 1, as well as their general description and expected beneficial impacts associated with their use. The promising AMPs list compiled in Table 1 was also divided into 5 classes of agriculture management practices, focused on: 1) soil; 2) nutrient; 3) pest; 4) water and 5) crop and land use change.

2.2. Selection of farms/plots

Each project partner with a Case Study Site selected 12 farms/plots in their SSA considering: 1) the two main representative farming systems of the area; 2) the two main representative soil types of the region and; 3) at least three different promising AMP's previously identified (Table 1). In this context, we consider the plot/farm as a uniform land where a certain soil type is present and where the responsible farmer uses a certain AMP under a certain farming system As so, a maximum of 12 representative plots/farms were identified per project partner using the most promising AMPs.

2.3. Main soil threats in the SSAs

In order to identify the most relevant soil threats affecting the SSA, each Case Study Site project partner ranked the mains soil threats. The ranking 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 most promising practices were identified. After this, each research team responsible for the Study Site Area translated their general perception for the identified soil threats into a ranking going from 1 to 8 (the number of soil threats considered), where 1 represents the most severe and 8 the least severe soil threat. This ranking is therefore a result from each research team conclusions based on the farmers reality identified during the plots selection. The soil threats included erosion, soil organic matter (SOM) decline, nitrogen leaching, soil-borne pests and diseases, compaction, poor water holding capacity, salinization and poor structure. This list was

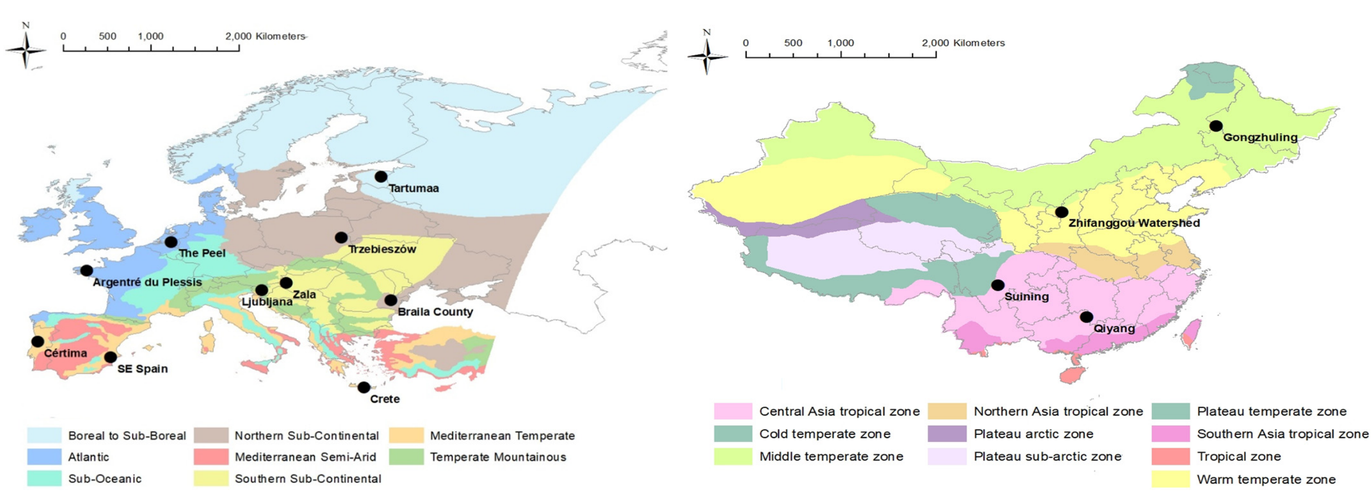

Fig. 1. – Study Site Areas location in Europe and China and distinct climatic zones. SE Spain includes plots located in the provinces of Valencia, Alicante and Murcia.

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 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)
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. a) 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]	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	a) Reduces risk of pest and weed infestations. - Improves distribution of channels or biopores created by diverse roots (various forms, sizes and depths).

(continued on next page)

Table 1 (*continued*)

AMP list	AMP description	Expected impacts/ecological benefits
(**Pest Managm.**)	Diversify species in rotation systems or grasslands	- 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.**)	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 (**Crop Managm.**)	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 (**Crop Managm.**)	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.

previously established during a workshop of the iSQAPER project, organized in Frick (Switzerland) in 2015, in order to establish which soil threats should be mostly considered in the agricultural context of Europe and China(ISQAPER, 2016).

3. Results

3.1. Farms/plots identified in SSAs of Europe and China

The intended variability in the identification of plots/farms per SSA, considering different farming systems and soil types, was not always possible along the pedoclimatic 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 (Table 2).

The number of plots/farms with promising AMP's identified in the SSAs 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).

In Europe, the majority of soils from the farms/plots identified were Cambisols (29%), Fluvisols (17%) and Luvisols (15%), while in China, Anthrosols were the most identified within the farms/plots identified (27%), followed by Cacilsols (23%) and Regosols (15%).

The most common promising AMP's in the identified plot/farms of 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%). However, it is important to refer that while some of the plots/farms identified only one promising AMP currently used by the farmer (71%), in some other SSAs farmers were using a combination of different AMP's at the same time (29%).

3.2. Variability of promising AMP's along the pedoclimatic gradient

In Europe, the majority of promising AMPs identified in plots/farms selected per SSAs were linked to *soil management* (representing 40% to 55%), with the exception of the Northern Sub-continental area where the *soil management* practices used were less representative (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. The *crop management* AMPs were identified in these three climatic regions and also in the Boreal to Sub-Boreal area, but always in small percentages (2%–12%) (Fig. 2).

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 where the same trend observed in Europe was present with the vast majority of AMPs linked to *soil management* (67%). However, *nutrient management* AMPs were absent from this case study area while *pest management* and *crop management* share the same importance (17%). 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

Table 2
Plots/farms identified in each SSA and respective climatic zones, soil type and AMP's. The meaning of the numbers in AMP column is presented in Table 1. SE Spain includes plots located in the provinces of Valencia, Alicante and Murcia.

SSA	Plot/farm	Climatic region	Soil type	Farming system	AMP	SSA	Plot/farm	Climatic region	Soil type	Farming system	AMP
De Peel	1.1	Atlantic	Anthros	Arable	2	Braila County	7.13	Sou SubCon	Cambisol	Arable	2;3;5;7;8;10;11;
	1.2	Atlantic	Anthros	Arable	10		7.14	Sou SubCon	Cambisol	Arable	2;3; 5;7;8;10;11
	1.3	Atlantic	Anthros	Arable	12		8.1	Nor SubCon	Cherno	Arable	2
Argentré du Plessis	2.1	Atlantic	Anthros	Arable	2		8.2	Nor SubCon	Fluvisols	Arable	8
	2.2	Atlantic	Anthros	Arable	2		8.3	Nor SubCon	Cherno	Arable	8
	2.3	Atlantic	Anthros	Arable	11		8.4	Nor SubCon	Fluvisol	Arable	11
	2.4	Atlantic	Anthros	Arable	8		8.5	Nor SubCon	Cherno	Arable	11
Cértima	3.1	Med Temp	Fluvisol	Arable	12		8.6	Nor SubCon	Fluvisol	Arable	7
	3.2	Med Temp	Fluvisol	Arable	5		8.7	Nor SubCon	Fluvisol	Arable	14
	3.3	Med Temp	Fluvisol	Arable	5		8.8	Nor SubCon	Cherno	Arable	14
	3.4	Med Temp	Fluvisol	Arable	5		8.9	Nor SubCon	Cherno	Pasture	17
	3.5	Med Temp	Fluvisol	Arable	11		8.10	Nor SubCon	Fluvisol	Pasture	17
	3.6	Med Temp	Fluvisol	Arable	11		8.11	Nor SubCon	Cherno	Pasture	18
	3.7	Med Temp	Cambisol	Perm	13		8.12	Nor SubCon	Fluvisol	Pasture	18
	3.8	Med Temp	Cambisol	Perm	2;4;9;12	Trzebieszów	9.1	Nor SubCon	Podzol	Arable	10
	3.9	Med Temp	Cambisol	Perm	1		9.2	Nor SubCon	Podzol	Arable	10
	3.10	Med Temp	Cambisol	Perm	2		9.3	Nor SubCon	Cambisol	Perm	12
	3.11	Med Temp	Podzol	Perm	2;4;9		9.4	Sou SubCon	Cambisol	Perm	12
	3.12	Med Temp	Podzol	Perm	2		9.5	Sou SubCon	Luvisol	Perm	12
	3.13	Med Temp	Podzol	Perm	2;14		9.6	Sou SubCon	Podzol	Arable	11
SE Spain	4.1	Med Temp	Cambisol	Perm	3;8		9.7	Sou SubCon	Podzol	Arable	11
	4.2	Med Temp	Cambisol	Perm	12		9.8	Sou SubCon	Leptosol	Arable	11
	4.3	Med SemAr	Cambisol	Arable	2;10		9.9	Sou SubCon	Luvisol	Arable	1
	4.4	Med Temp	Fluvisol	Perm	2;10		9.10	Sou SubCon	Luvisol	Arable	1
	4.5	Med SemAr	Regosol	Perm	2;3;10		9.11	Sou SubCon	Cambisol	Arable	11
	4.6	Med SemAr	Regosol	Arable	2;10; 11		9.12	Sou SubCon	Cambisol	Arable	10
	4.7	Med SemAr	Regosol	Perm	3;5;10		9.13	Sou SubCon	Podzol	Arable	10
	4.8	Med Temp	Regosol	Arable	1;5		9.14	Nor SubCon	Podzol	Arable	8
	4.9	Med Temp	Regosol	Arable	10;11; 14		9.15	Nor SubCon	Podzol	Arable	10
	4.10	Med Temp	Regosol	Perm	2;10	Tartumaa	10.1	Boreal	Luvisol	Pasture	10;18
	4.11	Med SemAr	Regosol	Arable	11;12		10.2	Boreal	Luvisol	Pasture	3
	4.12	Med SemAr	Cambisol	Arable	10;11		10.3	Boreal	Luvisol	Pasture	3;10
Crete	5.1	Med Temp	Calcisol	Perm	1		10.4	Boreal	Luvisol	Arable	3;10
	5.2	Med Temp	Calcisol	Perm	1		10.5	Boreal	Luvisol	Pasture	3;10
	5.3	Med Temp	Cambisol	Pasture	11		10.6	Boreal	Luvisol	Arable	10;11
	5.4	Med Temp	Calcisol	Perm	6		10.7	Boreal	Cambisol	Arable	2;11
	5.5	Med Temp	Calcisol	Arable	18		10.8	Boreal	Gleysol	Arable	2
	5.6	Med Temp	Cambisol	Arable	18		10.9	Boreal	Luvisol	Arable	2
	5.7	Med Temp	Regosol	Pasture	18		10.10	Boreal	Luvisol	Arable	2;11
	5.8	Med Temp	Leptosol	Perm	1		10.11	Boreal	Luvisol	Arable	1
	5.9	Med Temp	Regosol	Perm	1		10.12	Boreal	Histosol	Pasture	3

(continued on next page)

Table 2 (*continued*)

SSA	Plot/farm	Climatic region	Soil type	Farming system	AMP	SSA	Plot/farm	Climatic region	Soil type	Farming system	AMP
	5.10	Med Temp	Calcisol	Perm	1		10.13	Boreal	Histosol	Pasture	3
	5.11	Med Temp	Leptosol	Pasture	18		10.14	Boreal	Luvisol	Arable	1;11
	5.12	Med Temp	Cambisol	Pasture	18	Qiyang, Hunan	11.1	Cen.Asia tro	Regosol	Perm	10;12
Ljubljana	6.1	Sou SubCon	Fluvisol	Arable	8		11.2	Cen.Asia tro	Acrisol	Arable	12;15
	6.2	Sou SubCon	Fluvisol	Arable	14		11.3	Cen.Asia tro	Regosol	Arable	9;12;14
	6.3	Sou SubCon	Fluvisol	Arable	11		11.4	Cen.Asia tro	Acrisol	Arable	9
	6.4	Sou SubCon	Fluvisol	Arable	10		11.5	Cen.Asia tro	Acrisol	Perm	11
	6.5	Sou SubCon	Fluvisol	Arable	4		11.6	Cen.Asia tro	Regosol	Arable	15
	6.6	Sou SubCon	Fluvisol	Pasture	18		11.7	Cen.Asia tro	Regosol	Arable	10;12
	6.7	Sou SubCon	Cambisol	Arable	7	Suining, Sichuan	12.1	Cen.Asia tro	Anthros	Arable	5
	6.8	Sou SubCon	Cambisol	Arable	12		12.2	Cen.Asia tro	Anthros	Arable	9
	6.9	Sou SubCon	Cambisol	Arable	11		12.3	Cen.Asia tro	Anthros	Arable	10
	6.10	Sou SubCon	Cambisol	Arable	10		12.4	Cen.Asia tro	Anthros	Arable	10
	6.11	Sou SubCon	Cambisol	Arable	4		12.5	Cen.Asia tro	Anthros	Arable	5
	6.12	Sou SubCon	Cambisol	Pasture	18		12.6	Cen.Asia tro	Anthros	Arable	2
	6.13	Sou SubCon	Gleysols	Arable	2		12.7	Cen.Asia tro	Anthros	Arable	2;5
Zala	7.1	Sou SubCon	Cambisol	Perm	5;8	Zhifanggou Watershed	13.1	Cold. SemAr	Calcisol	Arable	11
	7.2	Sou SubCon	Luvisol	Arable	5;7;10;11		13.2	Cold. SemAr	Calcisol	Arable	6
	7.3	Sou SubCon	Cambisol	Arable	2;5;6;7;10; 11		13.3	Cold. SemAr	Calcisol	Perm	4
	7.4	Sou SubCon	Cambisol	Perm	5		13.4	Cold. SemAr	Calcisol	Pasture	17
	7.5	Sou SubCon	Luvisol	Arable	2;5;7 11		13.5	Cold. SemAr	Calcisol	Arable	4
	7.6	Sou SubCon	Cambisol	Arable	2;5;7;10;11		13.6	Cold. SemAr	Calcisol	Arable	5
	7.7	Sou SubCon	Cambisol	Perm	6;10	Gongzhuling, Jilin	14.1	Mid.Temp	Phaeo	Arable	5
	7.8	Sou SubCon	Luvisol	Arable	2;5;7;8;10; 11;13		14.2	Mid.Temp	Phaeo	Arable	1
	7.9	Sou SubCon	Cambisol	Arable	4;5;7;9;11		14.3	Mid.Temp	Phaeo	Arable	10
	7.10	Sou SubCon	Cambisol	Arable	2;5;7;10;11		14.4	Mid.Temp	Cherno	Arable	5;14
	7.11	Sou SubCon	Cambisol	Perm	6		14.5	Mid.Temp	Cherno	Arable	14
	7.12	Sou SubCon	Luvisol	Arable	2;5;7;8;11		14.6	Mid.Temp	Cherno	Arable	10

Med Temp: Mediterranean Temperate, Med SemAr: to Mediterranean Semi-Arid, Sou SubCon: Southern Sub-Continental, Nor SubCon: Northern Sub-Continental, Cen.Asia tro: Central Asia tropical, Cold.SemAr: Cold Semi-Arid and Mid.Temp: Middle Temperate. Anthros: Antroposol, Cherno: Chernozem, Phaeo: Phaeozem. Perm: Permanent farming systems.

were predominantly linked to *soil management* (43%) followed by *nutrient management* (29%) and *water management* (29%) (Fig. 2).

In the SSAs, both European and Chinese farmers use promising AMP's 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 farmers in the study areas considered here. Its representation is rather low (4 to7%), although its absence in regions such as the Mediterranean Semi-arid is due to the limitation of plots/farms identified within this climatic region.

3.3. Soil threats in SSA

In the Atlantic region, main soil threats are nitrogen leaching, soil-borne pests and diseases and compaction. In the Mediterranean temperate the main problems are erosion, SOM decline, compaction, poor structure and salinization. In the Southern sub-continental region, however, the main 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 (Table 3).

In China, given the limited number of SSAs, it is difficult to observe a consistency within the climatic regions. 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 area also shows problems with compaction and soil-borne pests and diseases while Suining area shows also problems with poor water holding capacity. The Warm temperate region, represented by

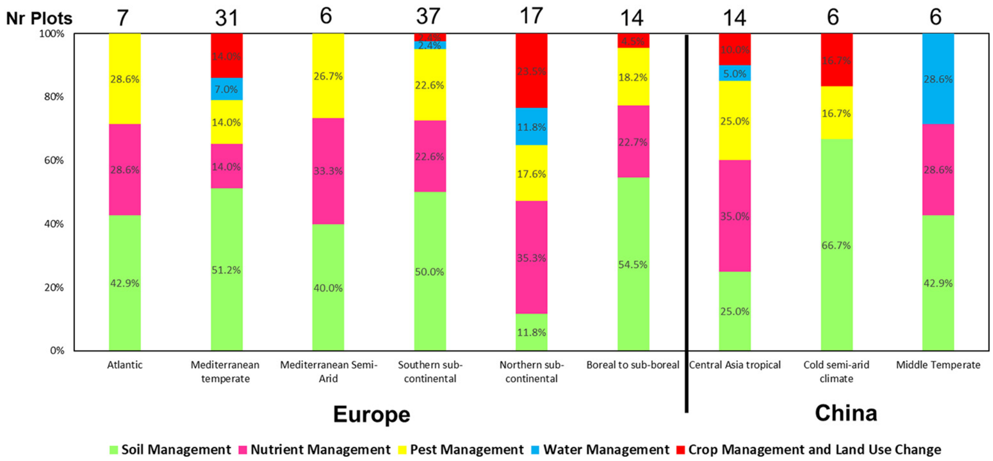

Fig. 2. Promising AMPs distribution categories in Europe and China grouped by climatic region.

Table 3
Soil threats severity grouped by climatic zone in Europe (a - top) and China (b - bottom), 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.

a)	Atlantic		Mediterranean Temperate			Southern Sub-Continental		Northern Sub-Continental		Boreal
SOIL THREAT	**1 . De Peel**	**2 . Argentré du Plessis**	**3 . Cértima**	**4 . SE Spain**	**5 . Crete**	**6. Ljubljana**	**7 . Zala**	**8 . Braila County**	**9. Trzebieszów**	**10 . Tartumaa**
Erosion	8	-	**2**	**3**	**1**	-	**1**		8	5
SOM decline	4	-	**2**	**1**	4	6	**2**	**3**	8	**1**
Compaction	**2**	4	**1**	**2**	6	5	**3**	4	7	**2**
Poor structure	-	-	6	**2**	5	7	5	4	4	**3**
Poor water holding capacity	5	-	8	5	7	**2**	-	5	**3**	6
N. leaching	**1**	-	8	-	5	**1**	6	6	7	4
Soil-borne pests and diseases	**2**	4	-	**3**	4	-	7	-	8	7
Salinization	-	-	8	**1**	**3**	-	-	**3**	-	-

b)	Central Asia tropical		Warm Temperate	Middle Temperate
SOIL THREAT	**11 . Qiyang**	**12 . Suining**	**13 . Zhifanggou**	**14 . Gongzhuling**
Erosion	**2**	**2**	**1**	-
SOM decline	**3**	4	**3**	**3**
Compaction	**3**	-	-	4
Poor structure	5	**3**	4	5
Poor water holding capacity	6	**3**	-	7
N. leaching	4	6	-	7
Soil-borne pests and diseases	4	6	-	5
Salinization	-	-	-	-

Zhifanggou study site shows also high incidence of the problems of erosion, SOM decline and poor soil structure while the Middle temperate zone, represented by Gongzhuling is more affected by SOM decline (Table 3).

4. Discussion

4.1. The need for soil protection and higher soil organic matter levels

Results from this study refer to a previously summarized list of promising AMP's (Table 1) identified along specific SSAs and may not be representative to other areas of Europe and China. However, since these SSAs are relevant areas for land management and are object of research for quite some time, the study of the 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 AMP's concerning soil and nutrient management practices (Fig. 2). This concern was transversal from Europe to China, although different promising AMP's where reported locally.

In Europe, the most identified promising AMP's denoted farmer's preoccupation with soil organic matter losses and soil erosion and aimed at soil protection, such as evidenced by the large adoption of minimum tillage practice (Hernanz et al., 2002; López-Bellido et al., 1997). 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 provided 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 have assure healthier crops which can resist easier to diseases (Lbpez-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 soil organic matter 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 required amount of crops. 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).

4.2. Future concerns about the adoption of promising AMP's

The perception of the interviewed farmers and researchers in the SSA's, regarding to soil threats, are generally in line with the distribution of the soil threats along Europe reported in previous studies (Orgiazzi et al., 2016; Panagos et al., 2015b; Tóth et al., 2008). 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 in this study. 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 that physical soil parameters (e.g. texture and pH) or geographical constrains (e.g. slope) play on the type of soil threat occurring in different regions. Furthermore, these parameters influence the type of management practices adopted by the farmers to overcome the situation.

The information provided in this study can be used as a basis for future decisions concerning the support of different AMP's to prevent soil degradation and to enhance soil quality. Policy makers should be aware that ongoing threats are menacing soil quality, and therefore agricultural productivity along Europe and China. The adoption of AMP's 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. Additionally, results can also be used to promote and support the management practices which can ameliorate soil threats that are not successfully addressed.

5. Conclusion

The present study identified the currently used promising AMPs (previously selected from a list of 18 AMPs) by farmers from 14 SSAs in Europe and China, along different pedo-climatic regions. 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 AMP's 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 AMP's that actively target damages from other soil threats such as salinization and nitrogen leaching.

Knowledge on main soil threats and AMPs easy to be accepted and implemented by farmers should be considered in future policy strategies, either to support farmers already adopting promising AMP's to promote soil quality and also to establish priorities for future incentives. Special attention is therefore given to the analysis of the impacts of the selected AMPs on soil quality in the selected plots/farms that we would like to publish in an oncoming manuscript.

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