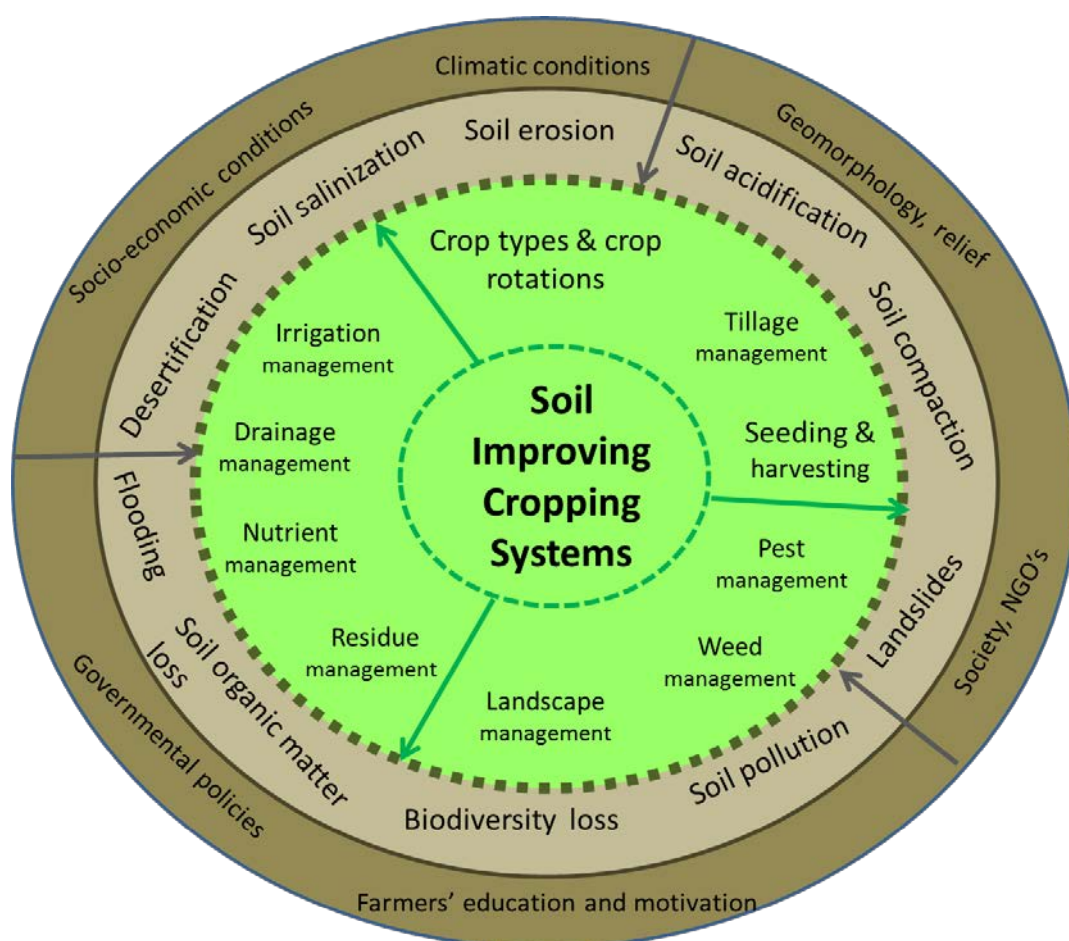


Soil-improving cropping systems

Non-technical summary of a review



The Challenge

Most farmers consider their land as main capital good that needs to be managed well. They know that crop yields and the economic and social benefits of farming depend in part on land management and soil quality. The better the soil quality and management, the higher the yields and economic and social benefits. While optimizing the benefits from land, farmers face volatile markets, variable weather conditions and influences from pest, diseases and policies, which make their tasks not easy. Suppliers, processing industries, extension services and research institutions at the same time try to support farmers in their strive. This support has increased during the last decades and will likely increase further because global food demand will nearly double during the next decades due to population increase.



View of poor soil management

The pressure to produce more food increases the pressure on land. The pressure on land is also increasing because the globalization of markets force farmers to lower costs and increase land and labour productivity, which is achieved commonly through upscaling, mechanization and increased inputs of non-factor inputs, i.e., fertilizers, irrigation and pesticides. Suppliers play an important role here; they deliver the inputs and provide guidance to optimize economic returns of the investments and inputs. The concerted actions have greatly contributed to increasing yields but at the same time have been conducive to soil degradation and to environmental pollution through e.g., leaching of fertilizers and pesticides, and erosion. Most farmers also know that land management is knowledge demanding and often costly, while effects on soil quality may not be visible immediately. Contracts between growers and processing industries and retailers demand for delivery on time, which may interfere with proper land management. Investments in soil quality are therefore not often prioritized, especially when land user rights and landowner rights are not well-established.

The global challenge therefore is to increase crop yields and to minimize soil degradation and environmental pollution simultaneously. Soil Improving Cropping Systems have been suggested as a strategy to halt soil degradation and environmental pollution recently. This document briefly summarizes the concept and opportunities of Soil Improving Cropping Systems. It is based on an extensive literature review¹

The Concept

The importance of selecting the proper crop rotations for soil quality and crop yield is known for millennia already, although the mechanisms are not always fully understood, even to-day. Farmers do understand the two-way relationships; some soils are better for some crops than other soils, and some crops are better for some soils than other crops. This knowledge has grown over centuries and is key to successful farming.

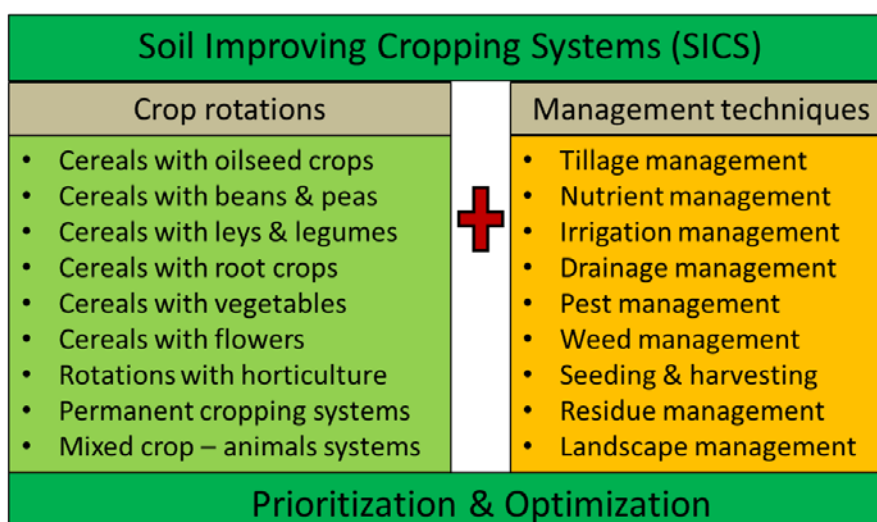


Figure 1. Concept of soil improving cropping systems; a combination of crop rotations and management techniques which have been prioritized and optimized so as to improve soil quality, profitability and sustainability of the cropping systems simultaneously.

The notion that management techniques influence soil quality and crop yields is of more recent date, because some of these techniques and the insights in these techniques have become available only recently. New crop varieties and management techniques have greatly contributed to the boost in crop yields from the second half of the 20th century, and have become key to successful farming. At the same time however, there has been a relative neglect of their effects on soil degradation and environmental pollution in some regions.

¹ <https://www.soilcare-project.eu/soil-improving-cropping-systems>

The premise of 'Soil Improving Cropping Systems' (SICS) is that there are cropping systems that improve soil quality and at the same time have positive impacts on profitability and sustainability. Cropping systems refer to a combination of crop types, crop rotation, and associated management techniques. There are many different crop types, crop rotations and management techniques, and hence also many cropping systems, but the diversity greatly depends on local socio-economic and environmental conditions. Soil improving cropping systems (SICS) are specific combinations of crop types, crop rotations and management techniques aimed at halting soil degradation and/or improving soil quality (Figure 1).



Wheat crop with buffer zone

The selection of specific crop types, crop rotations and management techniques is crucial for SICS. Management refers here to a coherent set of activities related to the cultivation of crops and land, and the handling and allocation of inputs, so as to achieve agronomic, economic, environmental, and social objectives. The management must be target oriented; targeted at achieving the objectives, targeted at minimizing soil degradation and improving soil quality. The management techniques refer to the combination of software and hardware; a total of nine management techniques have been distinguished (Figure 1), including tillage, seeding and harvesting, fertilization, irrigation, drainage, pest, weed, harvesting, residue, and landscape management. All these management techniques have to be practiced using the right techniques, in the right way at the right time. The concept of SICS emphasizes the proper combination of crop rotations and management techniques. It is broader than the concepts of 'sustainable soil management'² and 'soil conservation'³.

² FAO (2017). Voluntary Guidelines for Sustainable Soil Management. Food and Agriculture Organization of the United Nations, Rome, Italy, 26 pp.

³ Blanco H, and R Lal (2008) Principles of Soil Conservation and Management. Springer. ISBN: 978-1-4020-8708-0, 256 pp.

The selection, prioritization and optimization of crop rotations and management techniques depends also on the prevailing socio-economic conditions (markets, policies, culture, infrastructure) and environmental conditions (climate, geomorphology, soil quality and soil threats). Hence, understanding the situation and diagnosing the key factors are crucial. SICS are flexible; the crop rotations and management techniques are adjusted to objectives and conditions. The linkages between socio-economic and environmental conditions, soil degradation (soil threats) and soil improving cropping systems are illustrated in Figure 2. SICS have their basis in Liebscher's "Law of the optimum", which was formulated more than one hundred years ago⁴.

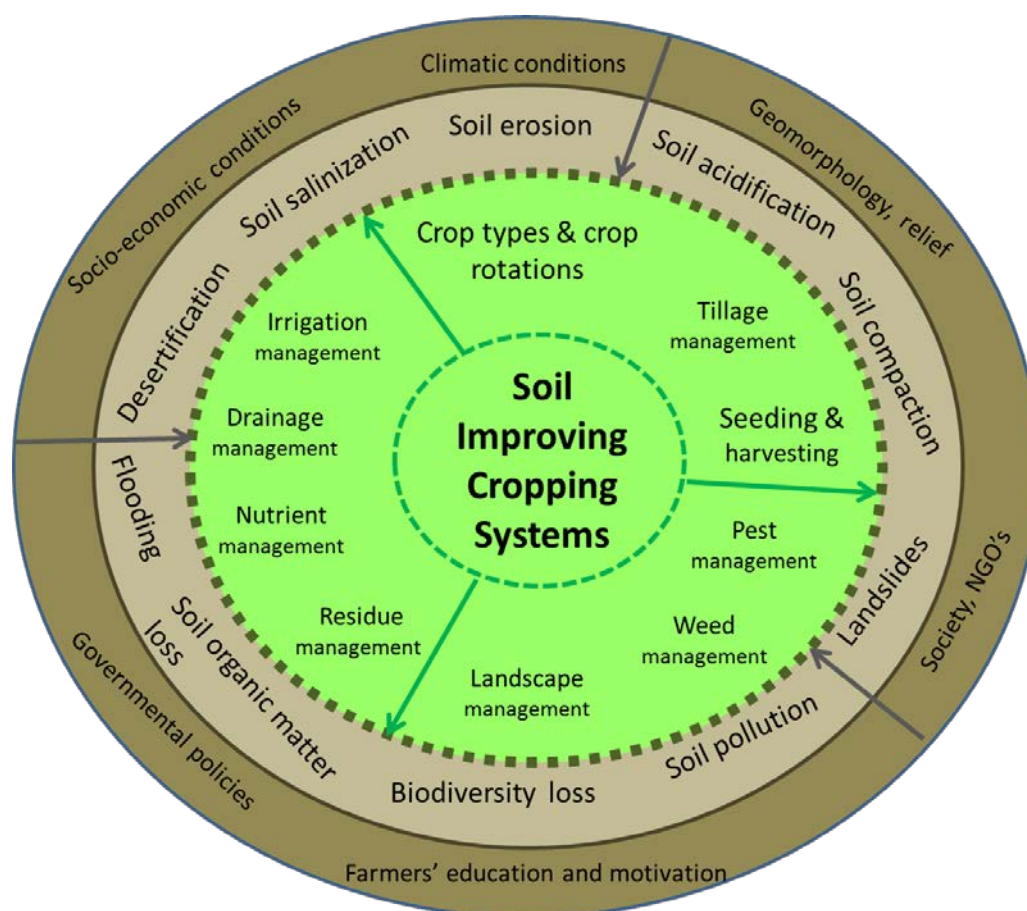


Figure 2. Illustration of the linkages between socio-economic and environmental conditions (outer circle), soil degradation (soil threats; 2nd circle) and soil improving cropping systems (inner circle). Influences of the socio-economic and environmental conditions are inwards directed, while the influences of soil improving cropping systems are outwards directed (indicated by arrows).

⁴ De Wit CT (1992) Resource Use Efficiency in Agriculture. Agricultural Systems 40, 125-151.

The Opportunities

Our review report provides evidence that SICS may indeed halt soil degradation and improve soil quality, and thereby improve the profitability and sustainability of the system. Typical examples include soil acidification-specific SICS, soil erosion-specific SICS and soil salinization-specific SICS. Top-soil acidification can be remediated cost-effectively through various liming materials, while selected crop types combined with controlled traffic may greatly lower the soil compaction pressure. Combinations of specific crops, crop rotations, tillage, residue management and landscape management may cost-effectively reduce the risk of soil erosion, and thereby improve soil quality, and the sustainability of the system. Smart combinations of irrigation, drainage, tillage and cropping may reduce soil salinization and improve soil quality and profitability.

Realizing the potential of SICS requires smart and site-specific combinations of crop rotations and management techniques. There is a huge spatial variation in soils and environmental conditions, and there are numerous cropping systems and ways management techniques can be combined and implemented. This diversity makes the realization of SICS knowledge-demanding. Depending on site-specific conditions, specific crop types and management techniques need to be prioritized in the optimization process.



Potatoes planted along the slope may be conducive to erosion

We observed evidence for trade-offs between investments in soil quality and short-term profitability, and between mitigation of soil threats and short-term profitability. Widening crop rotations and lowering fertilizer and pesticides uses may reduce the risks of soil compaction and declines in soil biodiversity and soil organic matter, but is often associated with yield penalties. The obvious response is then to reconsider the selected crop rotation

and management techniques and redo the optimization. Conversely, root crops are highly profitably in general, but often have negative impacts on soil quality. Evidently, not all cropping systems are soil improving and not all SICS are profitable in the short term.

The components of SICS have been analyzed for soil quality improvement in general and for soil threat mitigation specifically. These two approaches reflect different possible situations for the selection, prioritization and optimization of SICS. When there is clear evidence of soil degradation (signs of soil threats), components of SICS will have to be prioritized that remediate soil quality and prevent further soil degradation. When there are no clear signs of soil degradation, SICS may be introduced as a strategy to increase the robustness and resilience of the cropping system against uncertain external pressures and shocks. In the former case, SICS have the function of remediation, while the precautionary principle and stewardships are the drivers in the second case.

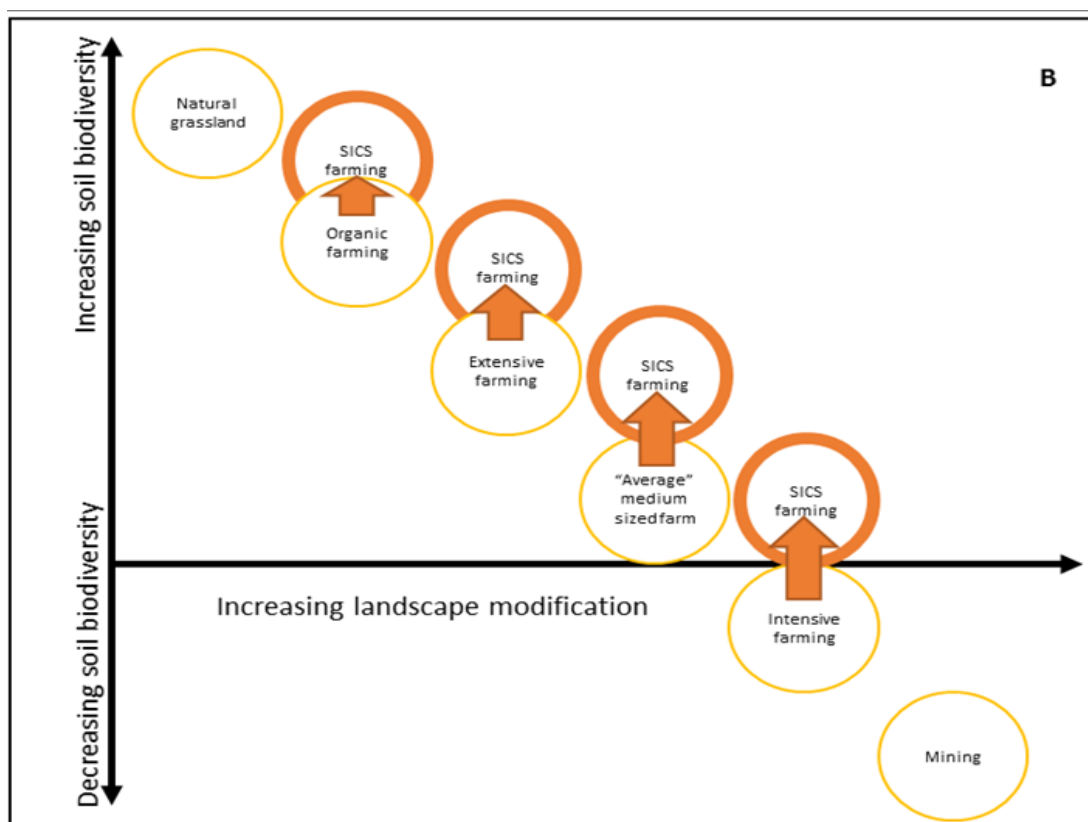


Figure 3. Visualisation of the effect of different farming systems on soil biodiversity (light orange circles), and the effect soil improving cropping systems on soil biodiversity (bold orange circles)⁵

⁵ Crotty et al. in preparation

Soils are among the most biodiverse habitats on earth with millions of species in one field. Together these organisms participate in functions important to soil health, nutrient cycling and plant growth. Generally, soil biodiversity decreases as the soil is farmed more intensively. Our review provides evidence that soil biodiversity can be enhanced for each farming system, provided specific combinations of management techniques are prioritized (Figure 3). Most promising biodiversity-specific SICS relate to the diversification of crop rotation by providing a greater range of food sources, increasing soil organic matter, and reducing the build-up of soil-borne pathogens.

Table 1 highlights the components of soil threat-specific SICS that have to be prioritized to be able to make the SICS cost-effective. Note that crop rotations are relevant to all soil threats, emphasizing the important role of crop types and crop rotations in remediating and improving soil quality and halting soil degradation. Table 1 also reveals that soil biodiversity is affected by essentially all management techniques.

Table 1. Summary overview of soil threat-specific SICS; components of cropping systems that need to be prioritized for the prevention and/or remediation of soil threats (indicated by x).

Components of cropping systems		Soil threats									
		1. Acidification	2. Erosion	3. Compaction	4. Pollution	5. SOM decline	6. Biodiversity decline	7. Salinization	8. Flooding	9. Landslides	10. Desertification
A	Crop types & crop rotations	X	X	X	X	X	X	X	X	X	X
B	Nutrient management	X		X	X	X	X	X			
C	Irrigation management	X			X		X	X			X
D	Drainage management					X	X	X	X	X	
E	Tillage management		X	X		X	X	X	X		X
F	Pest management				X		X				
G	Weed management						X				
H	Residue management		X	X		X	X	X			X
J	Seeding & harvesting management		X	X			X				
K	Landscape management		X				X		X	X	X

Table 2 provides a summary of the effects of different management techniques on soil organic matter content, based on an extensive review of literature. The last column shows the mean annual increase in soil organic carbon storage; it ranges from 118 to 330 kg of organic carbon per ha per year, which is roughly equivalent to 200 to 600 kg of organic matter per ha per year. Cover crops have a remarkably positive effect on increasing soil organic matter content, and at the same time also contribute to reducing soil erosion and nitrate leaching. Evidently, cover crops are often a key component of SICS, but the growth of a cover crop is not always feasible and there are possible trade-offs with the growth of the main crop.

Table 2. Effects of management techniques on soil organic carbon (SOC) sequestration rates⁶.

Management technique	Number of comparisons	SOC sequestration rate (kg C ha ⁻¹ yr ⁻¹)
Recycled organic materials (manure)	108	298
No-tillage	457	279
Aboveground crop residue handling	258	118
Cover crops	187	330
Nitrogen fertilization	51	175

Our review report provides many examples of the beneficial effects of specific combinations of crop rotations and management techniques. However, an overall assessment of SICS cannot be found in literature yet, because the concept of SICS is new. Yet, there are many partial analyses of components of SICS and when combined a fuller picture emerges. An interesting example is shown in Figure 4; the beneficial effects of growing wheat in rotation. The yield benefit of crop rotation ranged from 150 to 1250 kg ha⁻¹ year⁻¹.

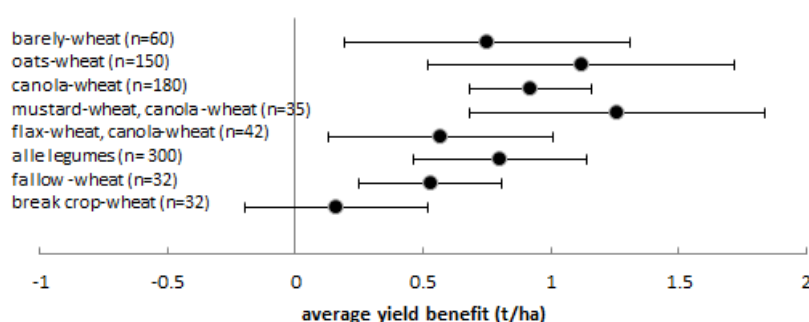


Figure 4. Benefit of growing wheat in rotation on wheat yield compared to growing wheat after wheat. Based on a meta-analysis of experiments in Europe, America and Australia, with 831 comparisons between wheat after wheat or wheat after other break crops⁷. Note, n is the number of comparisons, bars show 95% confidence interval.

⁶ Bolinder et al. in preparation.

⁷ Angus, J.F., Kirkegaard, J.A., Hunt, J.R., Ryan, M.H., Ohlander, L., Peoples, M.B., 2015. Break crops and rotations for wheat. *Crop and Pasture Science* 66: 523-552.

Summarizing, our review of the international literature provides evidence for SICS. Soils are vital to life on earth, and perform many critical functions within ecosystems and societies. However, soils are under pressure due to the intensification of land use in general and due to some poor management techniques. Appropriate site-specific combinations of crop type, crop rotations and management techniques can greatly alleviate the pressure of soil degradation and moreover improve soil quality and thereby profitability and sustainability of cropping systems. The site-specific selection, prioritization and optimization of crop rotations and management techniques is knowledge demanding. Our review also made clear that our knowledge of SICS is still incomplete. There are also trade-offs; some components may have positive effects on either soil quality, farm income, resource use efficiency and/or the environment impacts, but negative effects on other indicators. The key is therefore to understand the mechanisms and to decrease negative effects through changing the combination of components.

Table 4. Promising crop types and management techniques in soil threat-specific SICS.

Nr	Soil threat-specific SICS	Priority crop types	Priority management techniques
1	Acidification	No specific crop type	Liming, manuring
2	Erosion	Permanent groundcover, Deep-rooting crops Cereals with cover crops Alfalfa, Agroforestry	Zero-tillage, landscape management, contour traffic Proper timing of activities
3	Compaction	Deep-rooting crops, Cereals, perennial rye, alfalfa	Controlled traffic Low wheel load, low tyre pressures Proper timing of activities
4	Pollution	Biofuel crops Some fodder crops No leafy vegetables	No use of polluted inputs Tree lines to scavenge air-born pollution
5	Organic matter decline	Permanent groundcover, deep-rooting crops Cereals with cover crops, alfalfa	Minimum tillage, Residue return, Mulching Manuring
6	Biodiversity loss	Crop diversification	Manuring, minimum tillage, residue return, No pesticides, Minimal fertilization
7	Salinization	Salt-tolerant crops	Drainage Targeted irrigation Ridging
8	Flooding	Flooding-tolerant crops	Drainage Landscape management
9	Landslides	Deep-rooting crops, trees	Landscape management, No arable cropping
10	Desertification	Deep-rooting C4 crops	Landscape management

The next steps

Our review is a first step in the development of robust soil improving cropping systems, so as to improve soil quality and its functions, and at the same time to have positive impacts on the profitability and sustainability of cropping systems. Next steps include discussing possible

SICS with farmers and land managers to learn more about their suitability and adoptability. Testing of SICS in practice and further optimization of combinations of crop rotations and management techniques will be done within SoilCare across Europe during 2018-2020.

Table 4 provides an overview promising crop types and management techniques for addressing soil threats; selections of these crop types and management techniques will be tested. Intercropping, mixed cropping, alley cropping, strip cropping, double cropping may also have specific benefits for enhancing total crop yield, soil organic matter input, increasing biodiversity, and improving soil structure under certain conditions, but these have not been included yet because of possible barriers in terms of mechanization and labour efficiency.

Figure 5 outlines the foreseen process of the further optimization of the SICS in practice, through continuous 'learning by doing' cycle, which requires extensive monitoring.

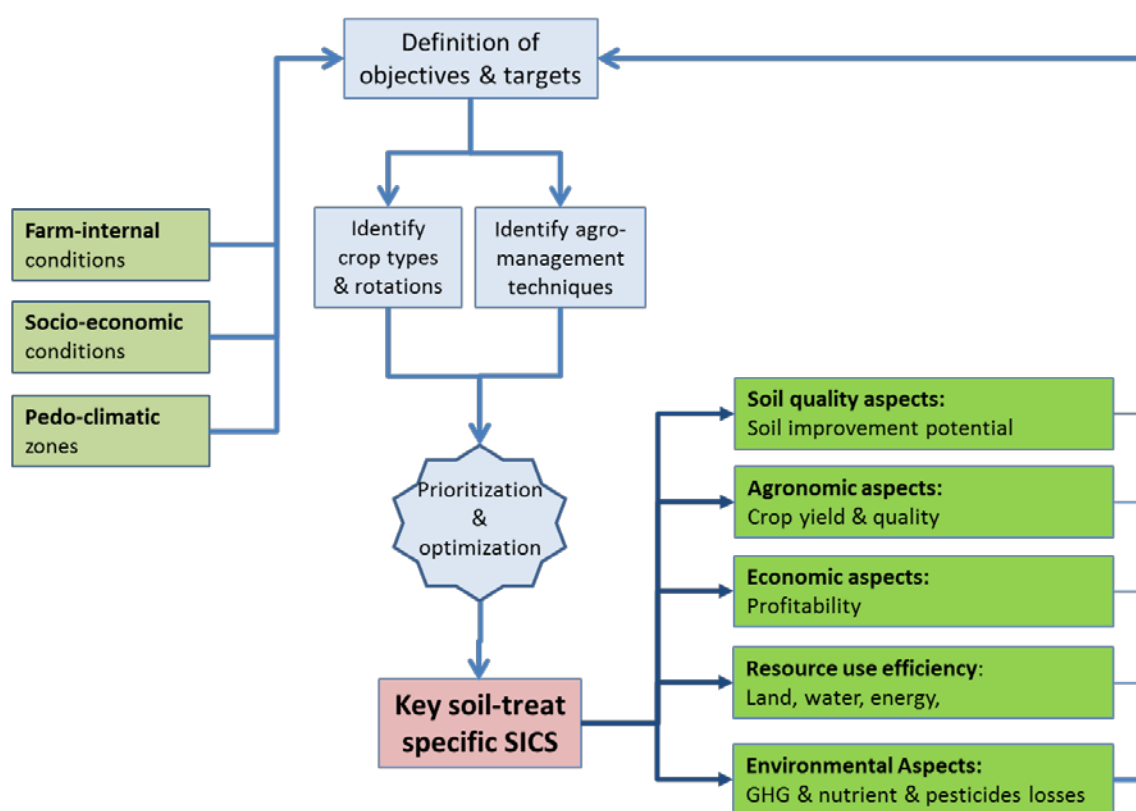


Figure 5. Conceptual outline of the further optimization of SICS in practice. The farmer, socio-economic and environmental conditions (on the left-hand side) define the initial objectives and targets of SICS, and are then tuned and modified on the basis of the outcome of the performance of SICS.