



SmartSOIL FACTSHEET

INCREASING SOIL ORGANIC MATTER THROUGH IMPROVED CROP ROTATION

WHAT IS IT?

A crop rotation refers to the sequential planting of different crops on the same parcel over the course of several growing seasons. Improved crop rotations refer to specially tailored crop rotation regimes, such as alternating deep-rooted and shallow-rooted plants or alternating a series of crops with a period of grassland (grass-ley) and introducing catch or cover crops (see Cover/Catch Crops FactSheet). These improved rotations can benefit farm soil by building soil organic matter, enhancing soil fertility and improving (deep) soil structure. Crop rotation can help replenish nitrogen in the soil, reduce erosion, and increase the water infiltration capacity of the soil. Practicing crop rotation can also provide a simple technique for managing and preventing weeds, pests and diseases from building up when land is continuously planted with the same crop (monoculture).

WHAT ARE THE BENEFITS?



- Enhance the carbon input to soil and sustain or improve soil organic matter levels
- Restore soil fertility and soil structure
- Reduced inputs (primarily mineral fertilisers) due to legumes
- Erosion control and flood risk management, weed, pest and disease management

Improving soil quality and preventing erosion and flooding

Intensive cultivation with the same crop over multiple years drastically decreases soil organic matter (SOM) of the soils on farms. Inclusion of specific crops in various crop rotation patterns can help to renew degraded soil by increasing soil organic matter and carbon sequestration⁽¹⁾ in the soil and possibly adding more nutrients as well. Setting up an appropriately tailored crop rotation regime which builds SOM and soil carbon can also improve and maintain soil quality and fertility over the short and long term, and prevent losses from fertile soil (erosion) or from plant or soil-related crop diseases.

Soil quality

Soil quality refers to soil attributes, soil functions and to the associated services delivered by soils. The soil quality may be described in terms of chemical, physical and biological properties. These characteristics determine the soils functions in terms of water and nutrient supply to plants as well as providing the physical and biological environment to reduce crop stresses and losses from diseases and pests. Soil quality therefore contributes to a range of ecosystems services that include sustaining crop yield, buffering water, recycling nutrients, reducing emissions of greenhouse gas and pollutants.

Building an appropriate crop rotation for your local context will depend upon the climate, soil type, and the goals which you want crop rotations to help achieve. For instance, in the Spanish case study region, implementing a crop rotation may in part aim to improve water management due to water scarcity. Thus, the design of the crop rotation will differ from other regions as well as the costs to implement it. The number of years over which the rotation is designed may differ drastically as well, with many farmers in the Scottish case study region implementing seven-year crop rotations.

Co-benefits

Type of benefit	Size of effect				Type of effect
	Grassland legume-based	Grassland non-legume-based	Grain legumes	Lucerne	
Promote soil biodiversity	+	+	+	+	Increases soil carbon and in some cases nutrient content and improves soil structure. Adds more below-ground biomass and enhances microbial and earthworm activity for enhanced fertility and porosity of (deeper) soil layers.
Erosion protection	+	+	+	+	Elimination of continuous arable cropping improves soil structure and reduces periods of bare soil, decreasing erosion. Rotational cropping acts as a natural soil stabiliser by providing cover, especially if the soil is normally left bare.
Prevent nutrient leaching (N, P)	0/+	0	0/+	0/+	Rotational crop planting which avoids bare soils may enhance nutrient catching by crops and preventing nutrients from being lost to the soil or groundwater. Increased nutrient content from incorporating N-fixing crops may enhance leaching and run-off if more fertiliser is applied, but by decreasing the need for mineral fertiliser application, they can reduce excess run-off and leaching.
Reduce soil emissions (nitrous oxide and ammonia)	0/+	0	0/+	0/+	Depends on the crop regime. Certain crops, such as alfalfa, clover or rapeseed, absorb and store nitrogen in the soil.
Promote above ground biodiversity	+	+	+	+	Increases rate of humus production and reduces soil compaction. Diverse fauna can have positive effects on natural pest control and surface carbon availability.

Legend: ++ maximum positive effect, + positive effect, 0 no effect, - negative effect, -- maximum negative effect

Examples of effective crop rotations:

Italy – Tuscany region (see also the Real-Life Cases in the SmartSOIL Toolbox)

- Loamy soil: wheat, sunflowers, maize or soybean, with soya preceded by hairy vetch (*Vicia sativa*)
- Heavy clay soil: wheat, sunflowers and clover (clover helps prevent diseases related to repeated planting of sunflowers)
- Sandy soil: durum wheat, rapeseed and soft wheat

Denmark – Sjælland region (see also the Real-Life Cases in the SmartSOIL Toolbox)

- Clay-silt soil: 4-year spring barley with under-sown grass, spring barley, and winter wheat
- Clay-silt soil: Spring barley, clover, 2-year grass, spring barley, winter wheat

increasing crop yields. Improvements in soil quality and soil productivity due to crop rotation have been shown to stimulate germination and crop growth rates, resulting in potential yield improvements. Among the SmartSOIL case studies, it was observed that farmers in Spain rotating wheat with legumes saw increases in their wheat yields between 32 and 46%. In general, however, significant yield improvements are not likely to result from crop rotation in the short term. The long-term benefits of crop rotation on yield are more likely, yet are not fully understood. See the table below for estimates of the yield impact from implementing crop rotations.

Reduction of Inputs

Depending on the crop rotation regime, improvements in the humus production rate in the soil and the concentration of key nutrients can reduce the amount of additional mineral fertiliser that is needed. Growing legumes before a cereal adds nitrogen into the soil which can be taken up by the following crop. As a result, the purchase of additional fertilisers may be reduced, resulting in cost savings.

Potential yield improvement

Especially where soil is poor, degraded, or normally left bare, adding legumes into the crop rotation regime provides an economical alternative to buying and applying mineral fertilisers and helps to build SOM and SOC, boosting soil productivity and

Soil organic carbon (SOC) in soil organic matter (SOM)
 SOM is composed of plant residues and microorganisms which breakdown and transform organic materials. This decomposition process produces or modifies SOM and increases SOC stocks in the soil. The process, which removes carbon dioxide from the atmosphere and adds carbon to the soil (via plant photosynthesis and decomposition and transformation), is called soil carbon sequestration. The amount of SOC gained depends on location (due to climate), crop productivity and crop type, amount of roots, crop residue and soil management.

More carbon benefits the formation of soil structure (stable aggregates) and results in: better aeration, more water availability, lower bulk density, friability and improved drainage. These in turn aid soil workability, reduce soil compaction and enhance infiltration capacity, thereby reducing run-off and erosion.

DRAWBACKS

Implementation may affect whether crop rotations offer enhanced nutrient availability for the subsequent crop. If legumes are incorporated into the rotation, the balance of available nitrogen in the soil may exceed what is needed and leach from the root zone before the plants are able to take it up. This is particularly a risk if leguminous cover crops within the rotation are incorporated during the autumn rather than the winter.⁽²⁾

Crop rotations require more expertise and planning than mono-cropping in terms of selecting effective crop sequences and ensuring that nutrient and weed control practices are adapted to the different crop requirements. The aim of crop rotation is to enhance the productivity of the entire system by planting crops in a series which maximises the soil fertility and nutrient benefits. Thus, cropping decisions do not depend upon crop prices which could incentivise repetitive planting.

Relationship between SOM/SOC, N fertiliser and water

N fertilisers and irrigation can help SOM (SOC) accumulate through increased crop production (increased organic input to the soil primarily through more root biomass and crop residues). The extent of the effect depends on having appropriate management in place (choice of tillage, cropping system, rotation), soil type, residue quality and on the response to weather and climate. In particular, fertilisation can help SOM accumulate in soils with low SOM levels and in poorly drained soils. Efficient N management is important and can lead to reduced emissions per unit of produce. However, irrigation combined with fertilisation or poorly timed irrigation may increase emissions, particularly of N₂O, and losses of N require additional fertiliser input later on.

WHAT ARE THE COSTS?

Implementation costs and cost-savings

Type of costs	Description of costs	Region					
		Denmark Avg (€/ha)	Italy Avg (€/ha)	Hungary Avg (€/ha)	UK Avg (€/ha)	Poland Avg (€/ha)	Spain Avg (€/ha)
Investment costs	Adoption of new crop types may require investment in new machinery or use of contractors	0	0	0	0	45.10	0
Operational costs		0	0	0	0	33.80	0
Other costs		0	0	0	0	0	0
Cost-savings	Avoided or reduced purchase of mineral fertilisers, pesticides, and herbicides	-47.70	-33.10	-18.70	-80.2	-54.5	-33.20
Total		-47.70	-33.10	-18.70	-80.2	24.40	-33.20

Calculations are based on data from EU Member States (FADN, SmartSOIL case studies, Natural Water Retention Measures project, 2014)

Impact on gross margin

In general, gross margins will increase due to the cost-savings mainly from applying less mineral fertiliser. Additionally, the crops included in the rotation should be profitable on their own. The extent to which gross margin may change depends on a variety of factors that are regionally specific, including the crop rotation regime applied, the variation in mineral fertiliser (as well as pesticide and herbicide) reduction, and costs associated with implementation. It is important to note that the estimates in the table above are general for the case study regions and may differ depending on the specific crop rotation design. Additionally, if crops are selected for which new or different equipment

needs to be purchased or contractors hired for implementation, the costs may reduce the extent of the cost-savings that crop rotations can provide.

Short-term increases in gross margin are also complemented by long-term soil organic matter improvements and potential yield increases. In determining average values for the EU, gross margin impacts depend on whether high, middle or low yield scenarios are considered. The range of outcomes shows that practicing crop rotations with legumes may increase gross margin by between 76.90 and 80.70 €/ha, and on average it is estimated that gross margin will increase by 78.90 €/ha.

WHAT DO FARMERS SAY?

Farmer from Midlothian, South East Scotland, UK

Farm system: Mixed (arable, sheep, over-wintered and store cattle)

Farm size: 214 ha

BROACHRIGG

“ I wanted to build the soil organic matter as well as improve the soil structure ... I wanted to bring the sowing dates forward as much as possible and can only do that through using rotation and reduced tillage

How long have you been farming?

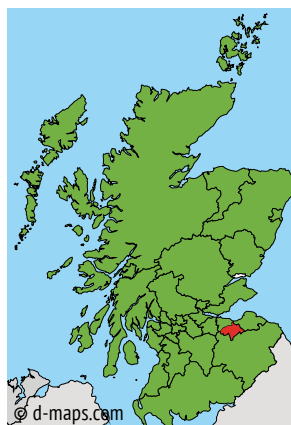
I have been farming since leaving college in 1999. I took up the tenancy of Broachrigg farm two years ago, although I have been farming parts of the farm before that. The quality of the calcareous gley soil was very poor when I took on the farm, for example there was no reincorporation of straw. As a result some fields had very little organic matter.

How have you incorporated the use of crop rotations into your farm management?

The current rotation includes winter oilseed rape, winter oats, winter wheat, spring barley and spring beans. If there is a second wheat in the rotation, this is mixed with triticale to mop up nutrients. Winter rye is planned but with the aim of early harvesting to allow time to incorporate manure into the soil and early planting of the following crop. Cover crops are grown as we aim to have something growing in the soil most of the time, for example the winter oilseed rape is sown with a cover crop of vetch.

Why did you decide to implement crop rotation?

I wanted to build the soil organic matter as well as improve the soil structure as lack of maintenance had caused the soil to become very fragile and the structure had collapsed. I wanted to bring the sowing



dates forward as much as possible and can only do that through using rotation and reduced tillage.

What challenges have you faced in applying crop rotation?

Sowing times for winter crops are earlier which is better; however, sowing is later for spring crops (as the ground needs to warm up) and this makes it difficult. We are also still on a learning curve about how to deal with cover crops before spring crops as leaving these growing can retain too much moisture in the soil.

What advice would you give to other farmers about using this practice?

You need to do your homework and be honest about your mistakes. Visit other farms and talk to other farmers about their experience.

Lessons Learned

- Crop rotation offers many synergies with other practices, including reduced tillage and residue management
- Significant benefits to soil organic matter, structure, and weed control when using reduced tillage are possible
- Consult your advisor to choose the rotational sequence that fits your objective on soil carbon, your soil type and climate

REFERENCES

- (1) West, T. O., & Post, W. M. (2002). Soil organic carbon sequestration rates by tillage and crop rotation. *Soil Science Society of America Journal*, 66(6), 1930–1946.
- (2) Möller, K., Stinner, W., Leithold, G. (2008) Growth, composition, biological N₂ fixation and nutrient uptake of a leguminous cover crop mixture and the effect of their removal on field nitrogen balances and nitrate leaching risk. *Nutrient Cycling in Agroecosystems* 82: 233–249.

For more detailed information about the practice implemented, benefits, and economic data, please refer to the Real-Life Cases in the SmartSOIL Toolbox:

<http://smartsoil.eu/smartsoil-toolbox>