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D3.2 Report on the cost-effectiveness of SOC measures

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Report on the cost-effectiveness of SOC measures

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Introduction

This document outlines our approach to, and the results of assessing the cost-effectiveness of measures to increase soil organic carbon (SOC) in arable farming. This analysis forms the core activity of task 3.2 and is a key link between work packages 2, 4 and 5 in that it integrates economic analysis into the biophysical assessment of SOC measures (work package 2) to inform the development of the SmartSOIL Decision Support Tool (work package 4) and both informs and is informed by stakeholder engagement (work package 5). The rationale of cost-effectiveness analysis (CEA) is to determine the prioritisation of SOC measures by determining the cost per unit of a chosen output measure, for example per tonne of CO_2 equivalent. This type of approach has been adopted at a number of scales and in different economic sectors (including industry and households) to inform decisions about the potential for greenhouse gas (GHG) abatement. The cost-effectiveness element informs decisions about the total abatement potential subject to economic constraints.

MacLeod et al. (2010) and Moran et al. (2011) report on an application of cost-effectiveness analysis to the potential abatement of GHG emissions to agriculture in the United Kingdom. Other examples of this approach include Pellerin et al. (2013) in France and Wang et al. (2014) in China. These approaches use marginal abatement cost curves (MACC) to rank abatement measures in terms of their cost-effectiveness (e.g. € per tonne of CO_2e abated) so that feasible policy interventions can be identified at either less than zero cost (i.e. 'win-win' measures) or at positive costs that are still below the social cost of carbon (or some policy relevant equivalent measure such as the shadow price of carbon that reflects mitigation targets). Consequently, the total 'cost-effective' abatement potential of the UK agricultural sector was identified. The MACC approach was applied across all UK economic sectors to allow a consistent assessment of aggregate abatement potential, and importantly to identify cost-effective sector level contributions to overall mitigation targets.

Figure 1 shows a simple MACC to illustrate the outputs of this type of analysis. The axes of the represent total abatement potential (horizontal) and cost-effectiveness (vertical). Each of the bars represents an individual abatement measure (for our SOC analysis these would represent a specific combination of crop and measure); the taller these bars the more cost-effective the measure, the wider the greater its abatement potential. There are four distinct areas with the MACC that are of interest to decision makers:

1. 'Win-win' measures, these measure lie below the horizontal axis and represent abatement at less than zero cost, i.e. implementing these measure will result in direct financial benefit.
2. In this area it is possible to achieve cost-effective emissions reductions. These measures incur a positive cost, but lie below the shadow price of carbon (SPC). Here there is potential for policy intervention to encourage uptake of measures as the social benefits exceed the private costs. Measures here could also be subject to private payments through offsetting schemes.

3. In the third area the costs of each measure begin to increase and are no longer cost-effective under current conditions.
4. As the majority of potential abatement has been achieved through lower cost measures, when we reach this fourth area only small additional abatement is possible and at increasingly high marginal cost.

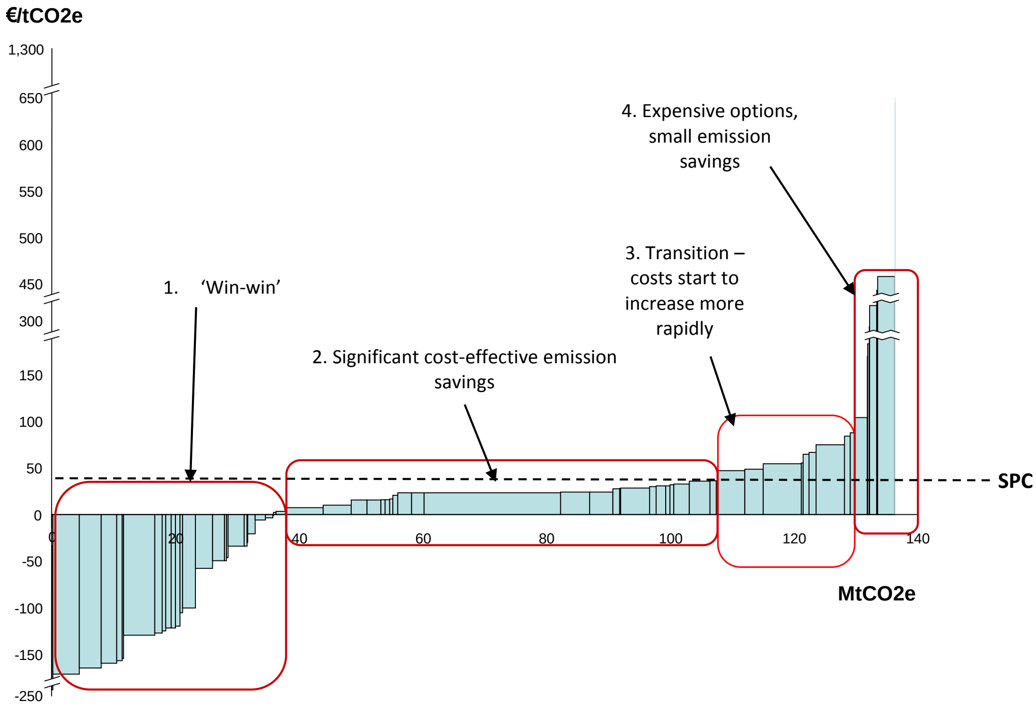

Figure 1 Example of a Marginal Abatement Cost Curve

The analysis by MacLeod et al (2010) was intentionally undertaken at an aggregate level and essentially treated the UK as a single farm without barriers to the implementation of measures. Also, the primary aim of the assessment was emissions abatement, which is of benefit to society as a whole rather for than individual farmers. Consequently, there may be a misalignment of social and private objectives; this in itself may act as a barrier to uptake of abatement measures. Extension initiatives such as Farming for a Better Climate[1] recognise this and focus on the benefits to farmers including greater efficiency and profitability. SmartSOIL also takes this approach in that the science is driven by identifying the private benefits of better SOC management such as higher yields or lower input requirements. As we discuss below, the choice of output measures may influence the acceptability of measures to farmers and the consequent outcomes in terms of uptake of measures and potential achievement of policy aims with respect to soil carbon.

[1] A Scottish Government funded advisory initiative delivered by SRUC: http://www.sruc.ac.uk/info/120175/farming_for_a_better_climate

Approach to cost-effectiveness analysis

In developing and refining our approach to the CEA we first considered the potential dissociation between the social and private costs and benefits of GHG abatement. In essence, the social benefits of the GHG abatement that are often the focus of policy are not fully realised by the private actors (farmers) who are implementing the abatement measures. We address this by focusing our measure of cost-effectiveness in a way that is of primary relevance to the farmer. As such we use change in gross margin per tonne of CO_2e abated as our cost-effectiveness metric. This is comes from a common assumption in modelling farm decision making that maximising gross margin is a key objective. Gross margin represents the surplus of output (price x quantity) over variable costs. We assume that fixed costs are less important for short-term decision making by definition. Our initial discussions with farm advisors as part of work package 5 also indicated that maximising yield was a key objective for farmers, and conceivably a 'change in yield per tonne CO_2e' cost-effectiveness metric could be used. However, this is intrinsically captured in our calculations of gross margin.

The initial task in the CEA was to create a long list of soil management measures. The key sources of information were the outputs from work package 2 (task 2.1) and other existing sources, e.g. the PICCMAT project. In consultation with the SmartSOIL case study partners the long-list was evaluated against applicability criteria:

- Farm or crop type
- Soil type
- Region/country (or a combination of the previous criteria)

The result was a list of feasible SOC measure and crop combinations for each of the case study regions based on the observed cropping activities in each region. These are outlined in Table 1. The combinations of measures and crops presented in the table are fully exhaustive, these reflect just those for which relevant information was available and could be identified by the case study partners.

Table 1 Combinations of SOC measures and crops in each case study region

	Case study region					
	Denmark (Zealand) [a]	**Hungary (Central Region)**	**Italy (Tuscany)**	**Poland (Mazovia)**	**Scotland (Eastern)**	**Spain (Andalucía)**
Cover/ catch crops	Wheat (winter) Wheat (spring) Barley (winter) Barley (spring)		Sunflower Maize	Oat Wheat (spring) Potatoes	Barley (winter) Barley (spring) Oats (winter) Oats (spring)	Maize (irrigated) Maize (irrigated) Almond (rainfed) Vineyard (rainfed) Olives (rainfed)
Zero tillage			Durum wheat Common wheat Maize Sunflower Barley		Wheat (winter) Barley (winter) Barley (spring) Oats (winter) Oats (spring) Rapeseed (winter)	Barley (rainfed) Barley (all)
Minimum/ conservation tillage	Wheat (winter) Wheat (spring) Barley (winter) Barley (spring)	Wheat (winter) Barley (winter) Barley (spring) Maize Sunflower Rapeseed	Durum wheat Common wheat Maize Sunflower Barley		Wheat (winter) Barley (winter) Barley (spring) Oats (winter) Oats (spring) Rapeseed (winter) Potato (ware) Potato (seed)	Barley (rainfed) Barley (all)
Residue management	Wheat (winter) Wheat (spring) Barley (winter) Barley (spring)	Wheat (winter) Barley (winter) Barley (spring) Rapeseed	Durum wheat Common wheat Maize Sunflower Barley	Rye (winter) Triticale (winter) Oat Wheat (winter) Wheat (spring)	Wheat (winter) Barley (winter) Barley (spring) Oats (winter) Oats (spring)	Wheat (rainfed) Wheat (irrigated) Barley (rainfed) Barley (irrigated)
Legumes	Wheat (winter) Wheat (spring) Barley (winter) Barley (spring)	Wheat (winter) Maize Sunflower Rapeseed		Rye (winter) Triticale (winter) Oat Wheat (winter) Wheat (spring)		Wheat (rainfed) Barley (rainfed)
Crop rotation	Wheat (winter) Wheat (spring) Barley (winter) Barley (spring)	Wheat (winter) Barley (winter) Barley (spring) Maize Sunflower Rapeseed				
Fertilisation with animal manures		Wheat (winter) Barley (winter) Barley (spring) Maize Sunflower Rapeseed				Barley (rainfed) Barley (irrigated) Maize (irrigated)
Optimised fertilisation						Wheat (rainfed) Wheat (irrigated) Barley (rainfed)
Green manures		Wheat (winter) Barley (winter) Barley (spring) Maize Sunflower Rapeseed				

[a] Note that for the legumes and crop rotation measures for Denmark we had no data on yield impacts so cost-effectiveness was not calculated.

Calculation of cost-effectiveness

For each measure we are expressing cost-effectiveness in terms of cost (£, € or other relevant currency) per tonne of CO_2e where the cost is the impact on the typical gross margin (output – variable costs) for each cropping activity in the case study region. In simple terms this is:

$$\Delta GM_{m,c} = YI_{m,c} \times Y_{c,p} \times P_{c,p} - VC_{c,p} - IC_{m,c} - DC_{m,c,p} - GM_c$$

Where:

$\Delta GM_{m,c}$ is the change in gross margin related to measure *m* and crop *c*

$YI_{m,c}$ is the yield impact (%) related to measure *m* and crop *c*

$Y_{c,p}$ is the typical yields for crop *c* and product *p* (products include the primary crop, i.e. grain, and any secondary outputs that can also be sold such as straw)

$P_{c,p}$ is the typical prices for crop *c* and product *p*

$VC_{c,p}$ is the variable production costs for crop *c* and product *p* before implementation of measure *m*

$IC_{m,c}$ is the implementation cost for measure *m* and crop *c* and can include investment costs (e.g. machinery, seed costs), operational costs (e.g. nutrient inputs, crop protection) less avoided costs (e.g. tillage)

$DC_{m,c,p}$ is the displacement cost of the measure *m* for crop *c* and product *p* and could include loss of production (e.g. switch from winter to spring crop) or loss of saleable product (e.g. cereal straw)

GM_c is the original gross margin for crop *c*

Cost-effectiveness for each measure *m* and crop *c* ($CE_{m,c}$) is then calculated as follows:

$$CE_{m,c} = \Delta GM_{m,c} / \Delta SOC_m$$

Where ΔSOC_m is the change in soil organic carbon associated with measure *m*. Alternatively SOC could be replaced by total GHG impact including direct and indirect energy and soil emissions (e.g. N_2O).

These calculations are made at the per hectare level, the impact on SOC or total GHG is then scaled up to the regional level by multiplying by the observed activity level (hectares planted) of each crop.

Data collection for cost-effectiveness estimation

We first carried out the cost-effectiveness analysis for the Scottish case study region. Here we describe that data collection and estimation process as an illustration of the approach that was then applied to the other case study regions. This can be generalised to any other region of interest. First we identified a set of measures relevant to arable farming in Eastern Scotland:

- Cover/catch crops
- Zero tillage
- Minimum/conservation/reduced tillage
- Residue management
- Legumes/N fixing crops either in rotation or undersowing

Published statistics based on the 2012 June Agricultural Census were used to identify the most significant crops in the Scottish case study region. The identified crops were winter wheat, barley (winter and spring), oats (winter and spring), winter oilseed rape and potatoes (ware and seed). Together these crops account for 90% of the arable area in the case study region. There is no lower threshold below which crops should not be included and decisions on significance should also consider the value of the crop (for example ware potatoes account for 4% of the area, but 34% of the gross margin in South East Scotland). The Scottish case study region fitted within existing boundaries for statistical reporting, where such boundaries do not relate directly to a region of interest then the nearest representative reporting unit should be used.

To assist with determining the scope of the collection of SOC, GHG and cost data for the crops and measures an assessment of relevance of measures to crops should be undertaken. For the Scottish case study this was a simple binary (1/0) matrix of crops and measures. A preliminary stakeholder workshop with farm advisors was held in Scotland which provided expert judgement on the applicability of measures both within the region and to specific crops. This judgement considered not only the geographical or climactic constraints on measures (e.g. available time to establish cover crops follow harvest) but also agronomic constraints such as the desire to control nutrient inputs where these may impact on crop quality (e.g. malting barley needs low nitrogen content which is difficult to control if using winter cover or legumes). Some knowledge was also obtained such as the general increase in short term contract farming which although difficult to model in our analysis adds an important qualitative narrative.

The elements of the gross margin calculation are presented in Table 2, this follows the layout used in the SRUC published Farm Management Handbook used for the Scottish case study. The detailed breakdown of cost elements is not needed for the cost-effectiveness calculation, but the following are needed to estimate the $\Delta GM_{m,c}$ above:

- Yield (t/ha)of primary (e.g. grain) and secondary (e.g. straw) outputs for each crop

- Price (£/€/other per t) of primary (e.g. grain) and secondary (e.g. straw) outputs for each crop
- Gross margin (£/€/other per ha) for each crop (sum of primary and secondary products)

For each of the combinations of crops and SOC measures we have used generic values from an existing UK study (ADAS, 2003) or other sources (e.g. PICCMAT) for estimates of the yield, SOC and GHG impacts. These are summarised in the Table 3 for the Scotland case study. SmartSOIL partners then reviewed these figures and provide relevant alternatives for the crops and conditions observed in the other case study regions. Our minimum requirement was for data on yield impacts and SOC effects as this would allow the estimation of cost-effectiveness for the SOC element of the measures. Although single values for SOC and GHG impacts were identified for a number of measures as part of task 2.1, we opted to use site or crop specific measures where possible as these were likely to more closely reflect conditions, crop types and soil types in the case study regions.

Table 4 presents the cost elements used in the Scottish case study region. These elements cover the cultivation costs in terms of investment (e.g. seed costs) and operational costs, any avoided costs such as reduced tillage costs are then subtracted to calculate the total cost impact (i.e. the $IC_{m,c}$ element in the equation above). Note that as the values in the table represent costs any negative values represent cost savings (i.e. they will have a positive impact on gross margin). Partners then reviewed these costs and provided relevant estimates for the crops and measures relevant to their case study regions.

Table 2 Elements of gross margin calculation (Scotland data, source SAC, 2013)

	Yield (t/ha)		Price (£/t)		Output (£/ha)			Variable costs (£/ha)					Gross margin (£/ha)
	Grain (1)	Straw (2)	Grain	Straw	Grain	Straw	Total	Seed	Fertiliser	Sprays	Other	Total	
Winter wheat	8	4.16	165	50	1320	208	1528	104	250	140	0	494	1034
Winter barley	7.5	4.15	145	50	1088	208	1295	96	234	91		421	874
Spring barley	5.5	2.87	145	50	798	144	941	83	177	80		340	601
Winter oats	7.5	4.74	175	50	1313	237	1550	86	204	44		334	1216
Spring oats	5	3	175	50	875	150	1025	86	172	105		363	662
Winter OSR	4		300		1200	0	1200	72	212	147		431	769
Potatoes (ware)	57	8	210	50	11970	400	12370	627	342	817	1890	3676	8694
Potatoes (seed)	35	8	195	75	6825	600	7425	1200	245	541	3405	5391	2034

1 The primary product is either grain for cereals or output of ware or seed potatoes

2 For cereals the secondary product is straw, for potatoes this refers to outgrades for average of ware and stockfeed for seed

Table 3 SOC and GHG impacts of measures

Measure		Yield effect (%)			SOC effect (t/ha) (1)	DE+IE effect (t/ha) (2)	GG (t/ha) (3)	Total GHG effect (t/ha)
		Mean	Range min	Range max				
Cover crop	Barley	100	90	120	0.88	0.1	0	0.98
	Oats	100	90	120	0.88	0.1	0	0.98
Zero till (4)		95	80	105	0.70	0.08	-0.49	0.29
Min till (4)		98	90	110	0.15	0.06	0.00	0.21
Residue mgmt	Winter wheat	0	0	0	2.29	0.00	-0.16	2.15
	Winter barley	0	0	0	2.29	0.00	-0.16	2.15
	Spring barley	0	0	0	2.29	0.00	-0.16	2.15
	Winter oats	0	0	0	2.29	0.00	-0.16	2.15
	Spring oats	0	0	0	2.29	0.00	-0.16	2.15

1 SOC and GHG impacts from PICCMAT for cover crops and ADAS (2003) for others
2 DE: direct energy (e.g. machinery operation); IE: indirect energy (e.g. embodied energy in N production)
3 GG: other GHG such as soil emissions of N_2O
4 Mean from ADAS (2003), range adjusted from Soane et al (2010)

Table 4 Cost elements of measures by crop type

Measure		Cultivation costs (1)		Avoided costs (e.g. tillage) (2)	Total input cost impact (£/ha)	Displacement costs (e.g. lost production) (3)
		Investment costs (e.g. seeds)	Operational			
Cover crop	Barley	115	25	0	140	354
	Oats	115	25	0	140	525
Zero till (4)			67	-102	-35	0
Min till (4)			50	-102	-52	0
Residue mgmt	Winter wheat	0	25	0	25	208
	Winter barley	0	25	0	25	208
	Spring barley	0	25	0	25	144
	Winter oats	0	25	0	25	237
	Spring oats	0	25	0	25	150

1 Rickson et al (2010)
2 Compared to deep ploughing (Morris et al, 2010)
3 Change in gross margin, shift from winter to spring crop (cover crops), or loss of straw revenue (residue management)
4 Mean from ADAS (2003), range adjusted from Soane et al (2010)

Limitations

There are a number of important limitations to the cost-effectiveness analysis which mean that the results of the cost-effectiveness analysis should be taken as indicative of the relative ranking of measures rather than absolute values.

- The analysis is static in that it considers the impact of the SOC measures for one year only rather than over the course of a rotation. Consequently, we have been unable to consider how SOC levels change over time and what the effect of periodic ploughing may be on long term SOC levels.
- Linked to this we have not accounted for the initial SOC concentration and consequently their ongoing impact on SOC levels, for example whether the marginal increments in SOC remain constant or decline as SOC increases. Similarly our static approach does not account for changes in yield impact as SOC changes or potential agronomic impacts such as improved soil structure and workability that might reduce costs.
- We have not fully modelled farmer decision making in that the changes in costs and yields associated with the different measures would be expected to change farm activities making uptake of the measures within each region more or less likely. This is an issue that will be addressed as part of task 3.4 where we will incorporate the data on measures into a farm level model. This has been developed for Scotland and its application to other case study regions will be explored.
- The barriers to uptake of measures have not been iterated back into the cost-effectiveness analysis, these will be important in determining the overall level of SOC increase that might be achieved. Part of task 3.3 is to explore policy options for incentivising uptake.
- There remain a number of key data gaps with respect to the impacts of the measures in terms of SOC and GHG, yield and costs. Where possible we have used data specific to the case study regions and/or the crops grown those regions, but in some cases it was necessary to transfer data from elsewhere. This is a general issue with the literature which is often only partial in its description of the impacts of measures. There are a number instances where data on yield impact were not available where we have made an assumption of 'no impact'.

Cost-effectiveness of SOC measures for the case study regions

In this section we present the results of the cost-effectiveness calculations for each case study region including the graphical representation of those results as MACCs of the type illustrated in Figure 1. The measures were discussed during the task 5.2 stakeholder workshops where the cost-effectiveness results and MACC diagrams were presented to farm advisors. Full details of those workshops can be found in deliverable 5.2. Of particular relevance to this task are the barriers to uptake of the SOC measures discussed during the workshops.

For each of the case study areas we present an example of the outputs from the cost-effectiveness analysis using the impacts of SOC levels for either mean or high yield impacts, this illustrates the sensitivity of the results to the impact on yield. The full tables of cost effectiveness results are presented in the appendix 1. For each case study region the analysis is undertaken at the scale of the region rather than for a typical farm, therefore the impacts on gross margin would be applied over the whole of each region and the SOC changes also apply across the region.

The cost-effectiveness analysis was undertaken without considering interactions between crops and measures. Previous examples of the type of analysis (e.g. MacLeod et al., 2010) specifically considered the interaction of measures where the abatement was first applied to the most cost-effective measure and system combination, the abatement potential of subsequent measures was then adjusted to account for abatement achieved by each preceding measure. Such an approach requires a detailed assessment of interaction factors which we have not been able to find the literature. To illustrate the potential impact of interactions we present two version of each MACC, one including all crops and measures combinations the other with only the most cost-effective measures for each crop. The former type of chart provides a simple ranking of cost-effectiveness by crop and measure but cannot be used to illustrate the full SOC abatement potential in each region due to the double counting of measures across the same crops. The latter chart provides a simple estimate of SOC abatement potential assuming that the most cost-effective measures are adopted for each crop.

This illustrates a further limitation of our analysis, namely that it is static and for a single year, essentially it is an estimate of the cost-effectiveness of the annual marginal increase in SOC for each crop and measure. This avoids the need to have data on current SOC concentrations in the soils for each region, or information on how many years of application are need to reach SOC saturation. Also, it does not consider longer term agronomic practices such as the intermittent used of inversion tillage. A final limitation of the analysis is that we do not model optimal cropping decisions, i.e. in response to the impacts of measures on gross margin, what cropping activities would be adopted to maximise gross margin? Instead we assume that cropping patterns remain as observed.

Note that several of the following figures have breaks inserted into the vertical axes to where there are extreme values.

Denmark - Zealand

Figure 2 presents the MACC for Denmark for all crops and measures for the 'mean' yield impact. There is a clear ranking of measures with minimum tillage being a 'win-win' option at a less than zero impact on gross margin. Despite a small decrease in yield for this measure there is a benefit in terms of reduced costs compared to conventional tillage. However, the width of the bars indicates that the SOC gains are relatively small. Residue management (i.e. straw incorporation) is the next ranked measure, this incurs a positive cost as straw is a valuable crop by-product and the measure effectively involves loss of income, the SOC impact can be relatively large depending on the crop. Cover crops are the least cost-effective largely due to the implementation costs of establishing the cover crop; the final two bars reflect the additional impacts of displacing winter crops for spring crops.

Figure 3 presents the most cost-effective measures for each crop in Denmark. As expected these are all related to the minimum tillage measure for the reasons discussed above. The scale on the x-axis indicates a total SOC impact of 188,000 tonnes (CO_2e) based on observed cropping patterns.

Figure 4 and Figure 5 present the MACCs based on the highest (positive) yield impacts for all crops and measures and the most cost-effective measures respectively. Although minimum tillage remains the most cost effective measure, the ranking of residue management and cover crops largely switch due to estimated 20% increase in yields associated with cover crops. We note though that we were unable to find data on the yield impact of residue management so assumed that yields were unchanged.

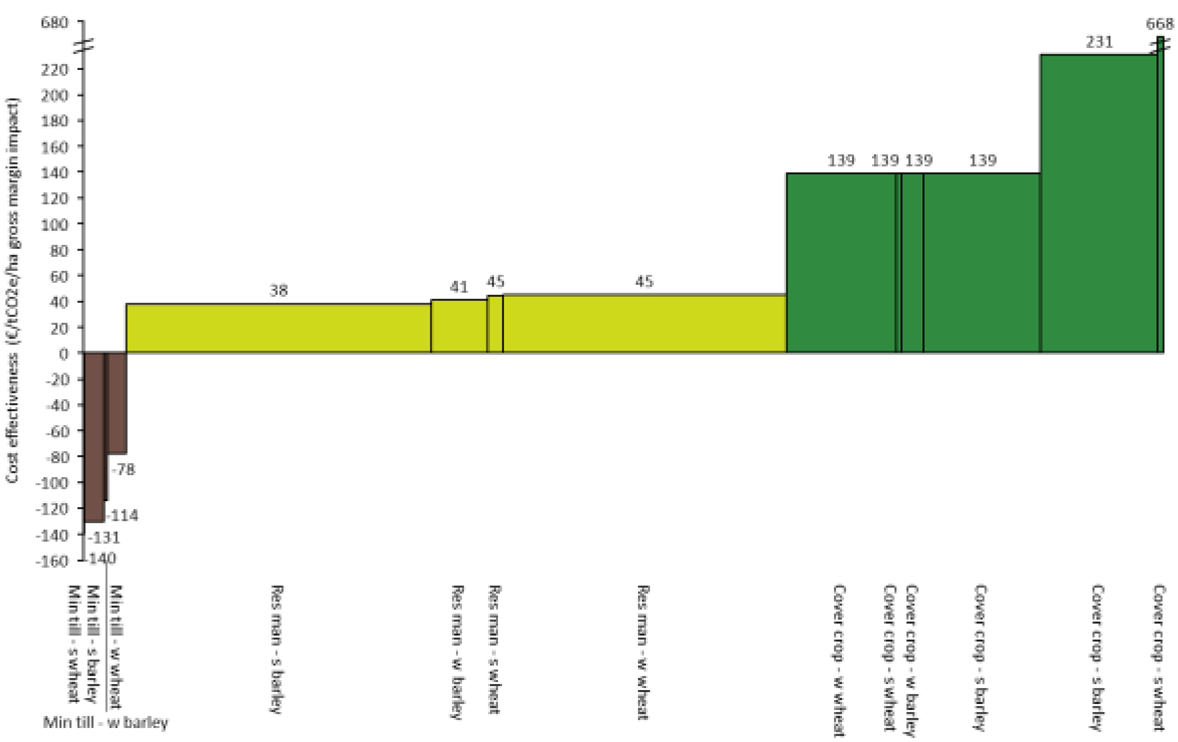

Figure 2 SOC MACC for Denmark – mean yield impact (all measures and crops)

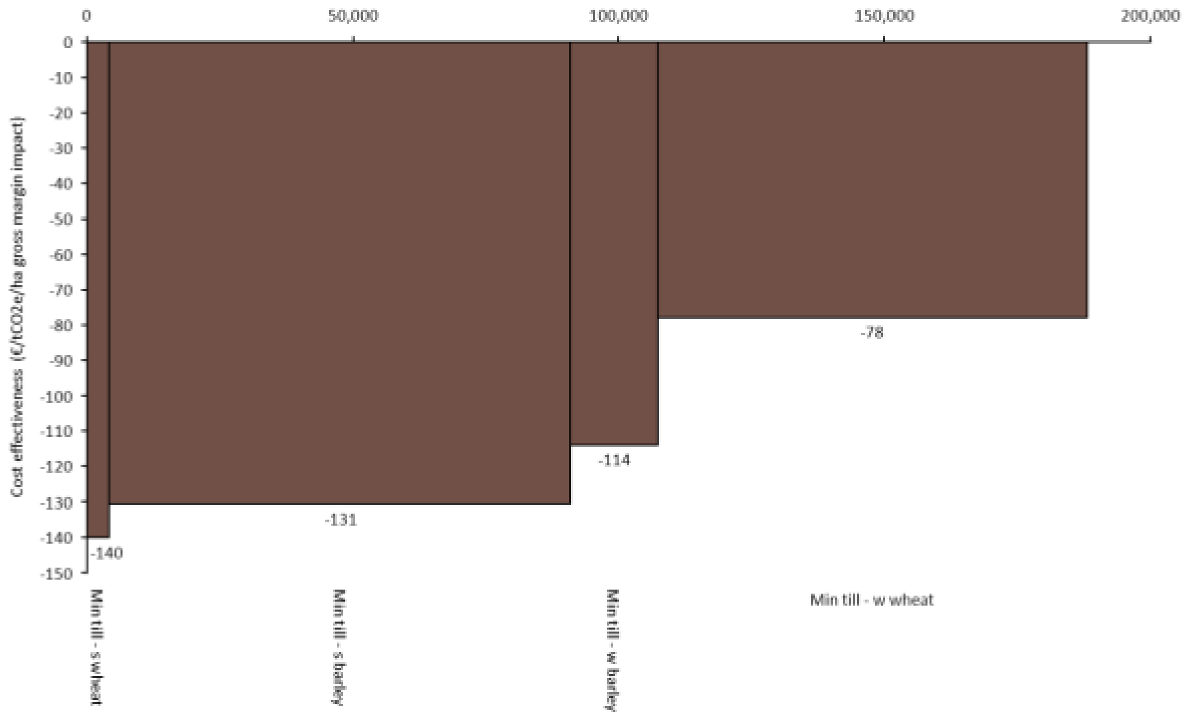

Figure 3 SOC MACC for Denmark – mean yield impact (best measure for each crop)

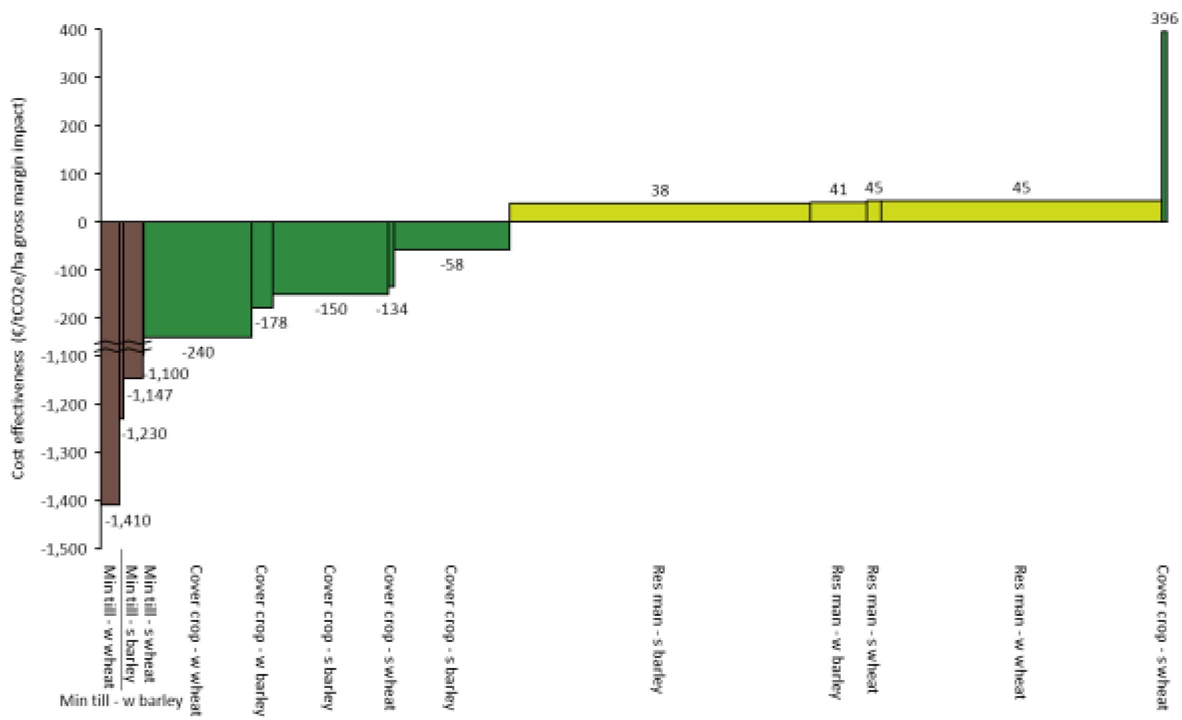

Figure 4 SOC MACC for Denmark – high yield impact (all measures and crops)

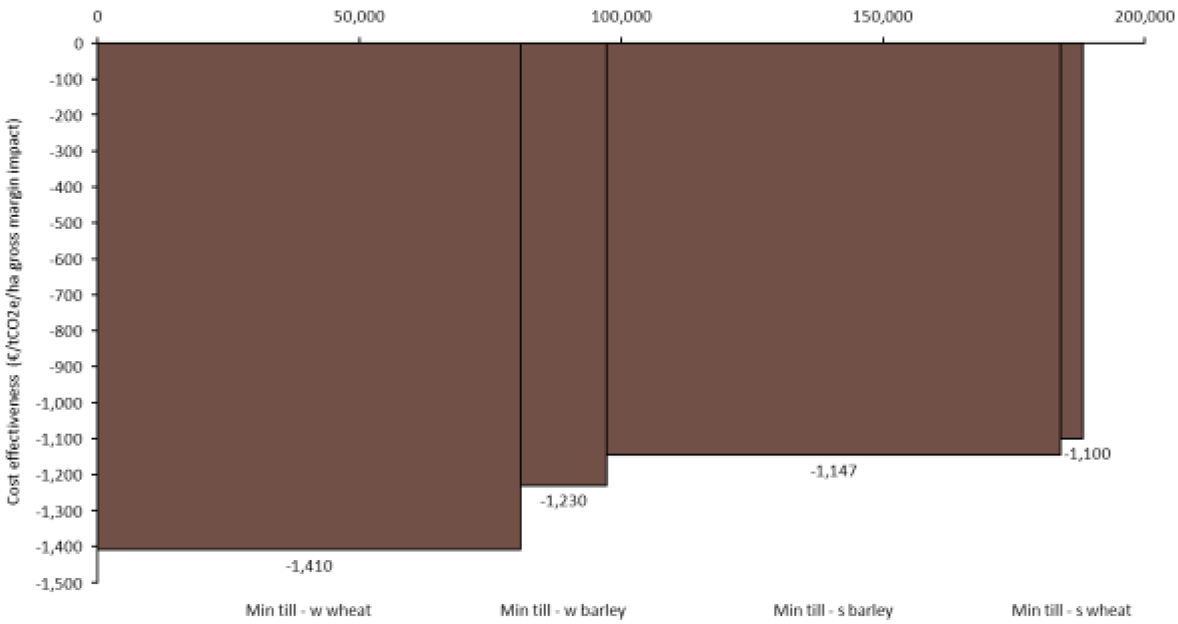

Figure 5 SOC MACC for Denmark – high yield impact (best measure for each crop)

Hungary – Central Region

The MACCs for Hungary under the mean yield impact assumption are presented in Figure 6 and Figure 7. By some margin the most cost-effective measures are the use of manures for winter wheat and maize, this is due in both cases to very high positive yield impacts (50% and 24% respectively). Applications of manure to other crops was also a 'win-win' although no data on yield impact were found, instead there was a cost reduction associated with this measure. As with Denmark, minimum tillage was also a 'win-win' measure. Residue management and green manure (we assume similar impacts on yield and cost as for cover crops) were associated with positive costs (i.e. reductions in gross margin) due to loss of revenue from straw and the establishment costs of the green manure. Considering only the most cost-effective measures for each crop (Figure 7) current cropping patterns indicate a potential annual SOC increase of 30000 tonnes in the case study region.

The used of the high (positive) yield impact estimates (Figure 8 and Figure 9) does not alter the ranking of the most cost-effective measures, although minimum tillage does become relatively more cost-effective. The higher yield impacts for green manure result in the same switching of rank with residue management as observed for cover crops in Denmark.

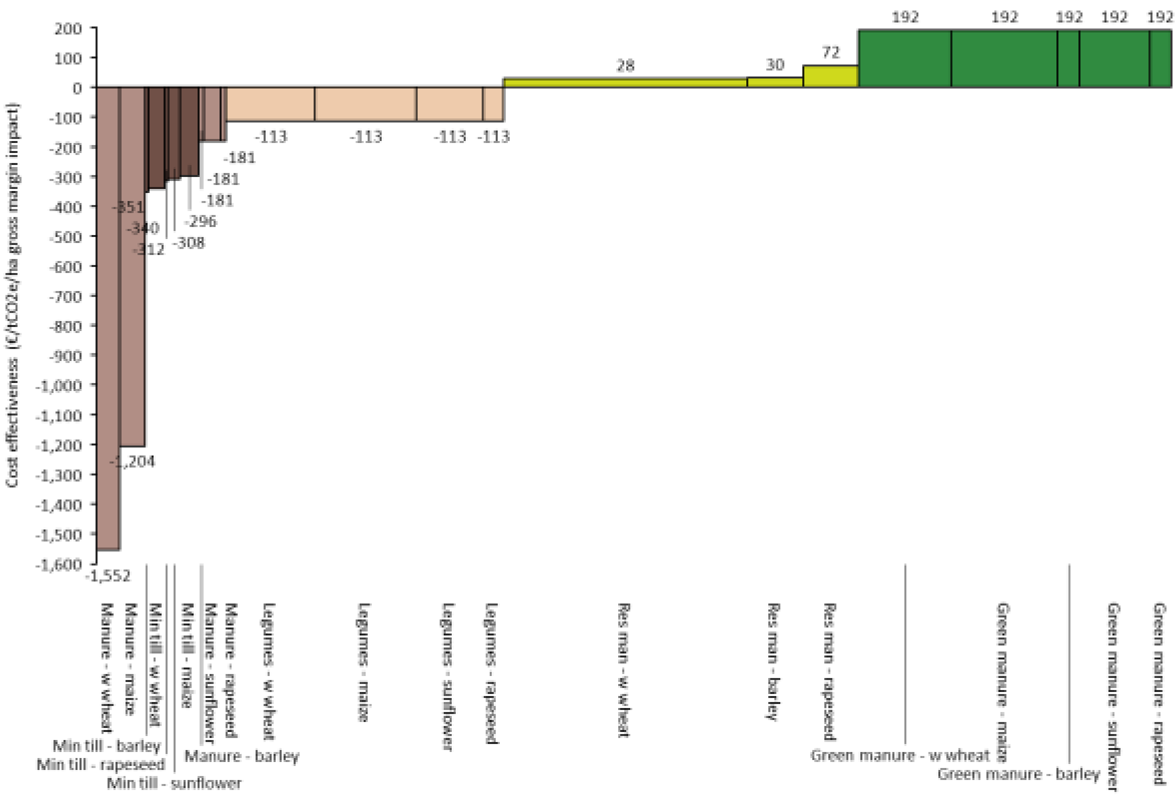

Figure 6 SOC MACC for Hungary– mean yield impact (all measures and crops)

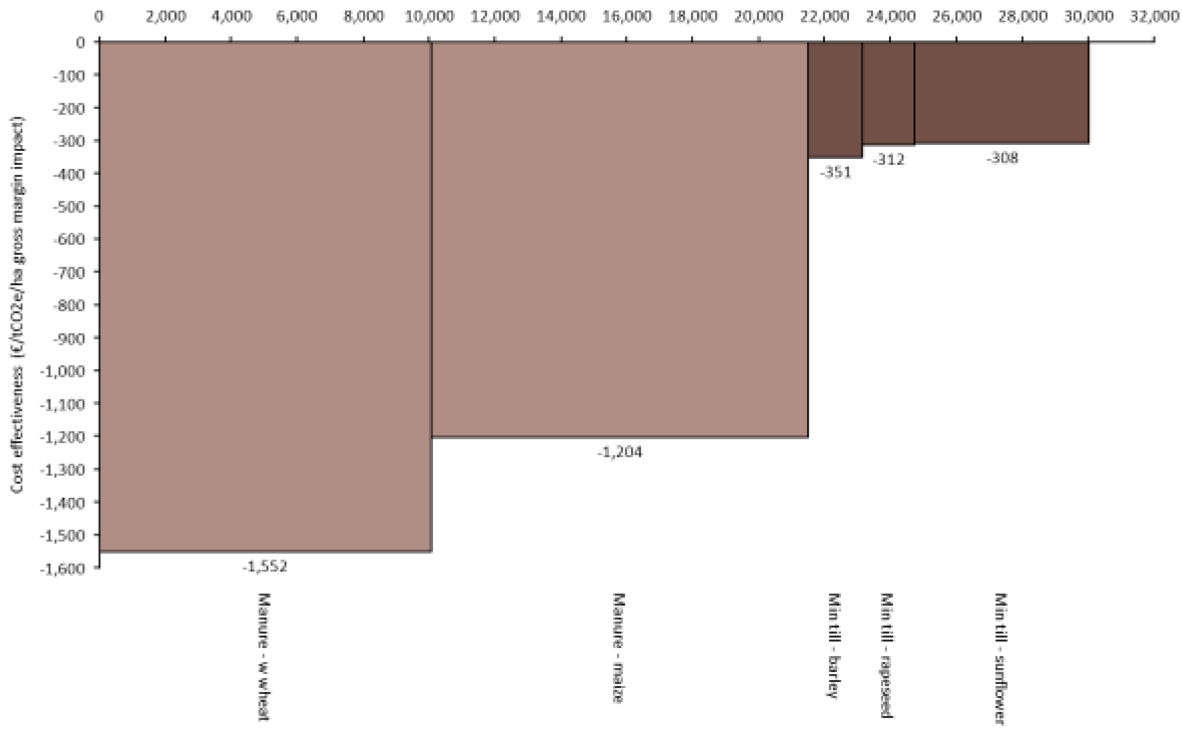

Figure 7 SOC MACC for Hungary – mean yield impact (best measure for each crop)

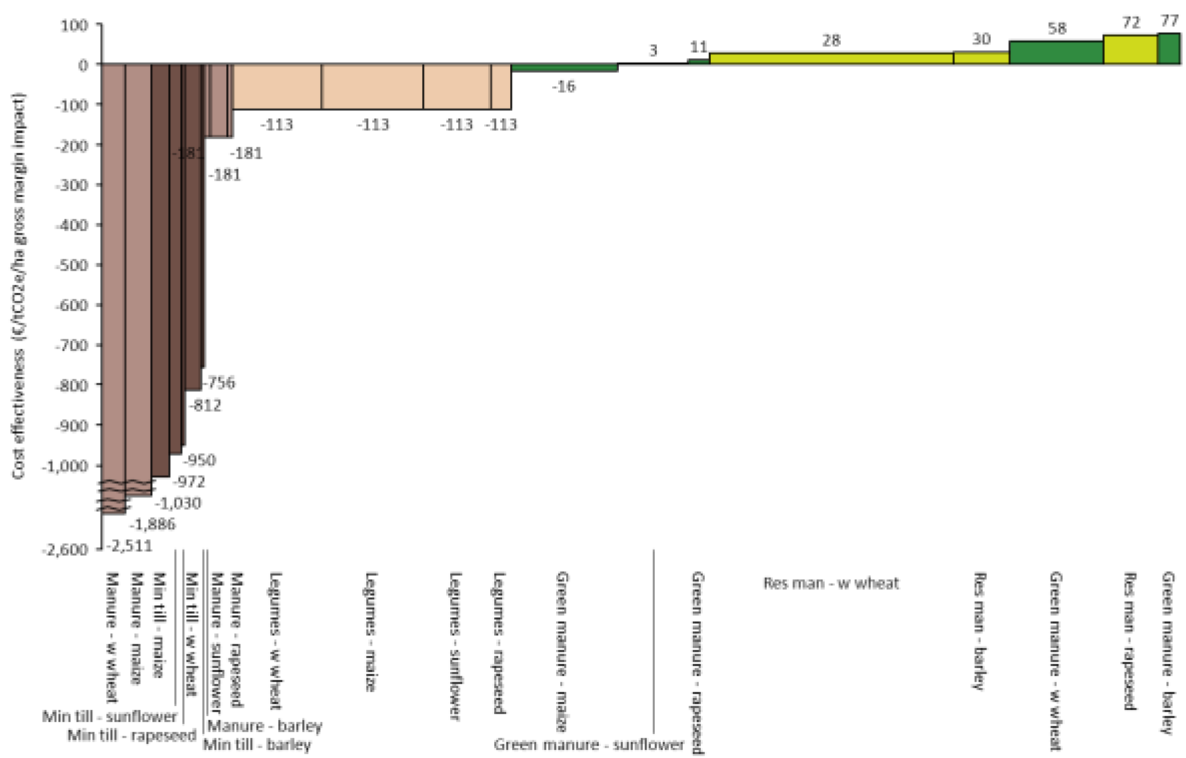

Figure 8 SOC MACC for Hungary – high yield impact (all measures and crops)

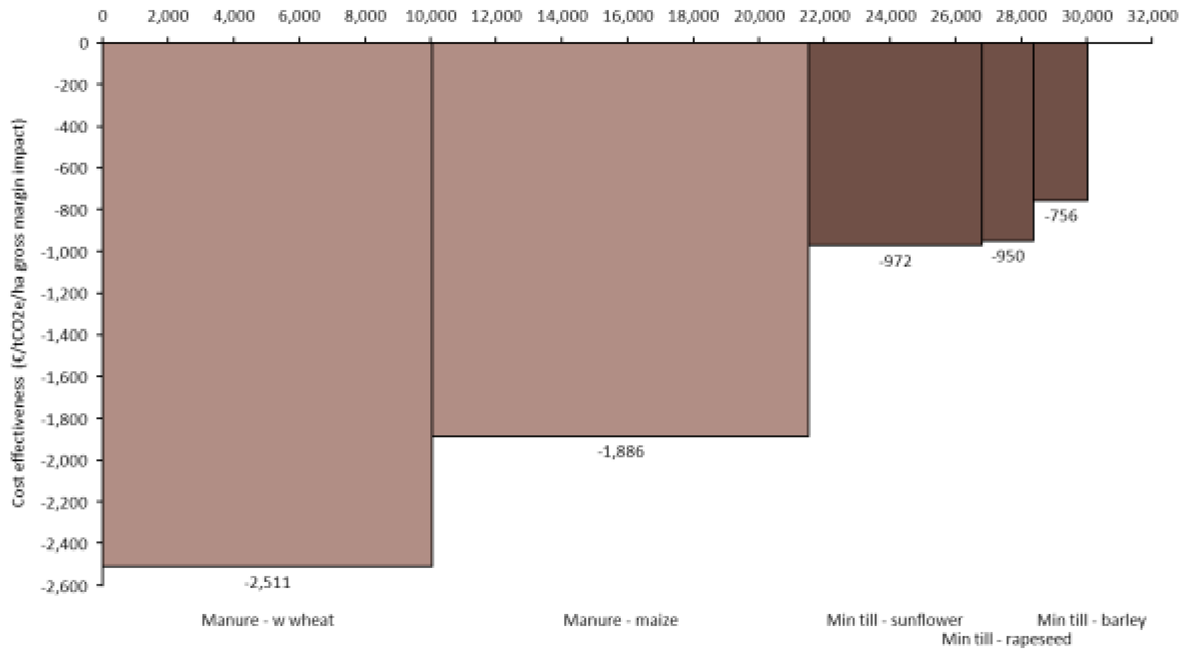

Figure 9 SOC MACC for Hungary – high yield impact (best measure for each crop)

Italy – Tuscany

Figure 10 presents the MACC for Tuscany for all crops and measures under the ‘mean’ yield assumption. This indicates that only minimum tillage for sunflower has positive impact on gross margin (i.e. negative cost). There is also a less clear ranking of measures with minimum tillage also being the least cost-effective when applied to durum and common wheat. Figure 11 indicates that only a very modest increase in SOC could be achieved at negative or small positive cost in the case study region at approximately 17000 tonnes at <€100 per tonne CO_2e.

The estimated cost-effectiveness under the high yield assumption is improved with both minimum and zero tillage for maize, sunflower and barley being ‘win-win’ combinations. However, when considering only the most cost-effective measures for each crop the potential for a negative cost increase in SOC is only 8600 tonnes.

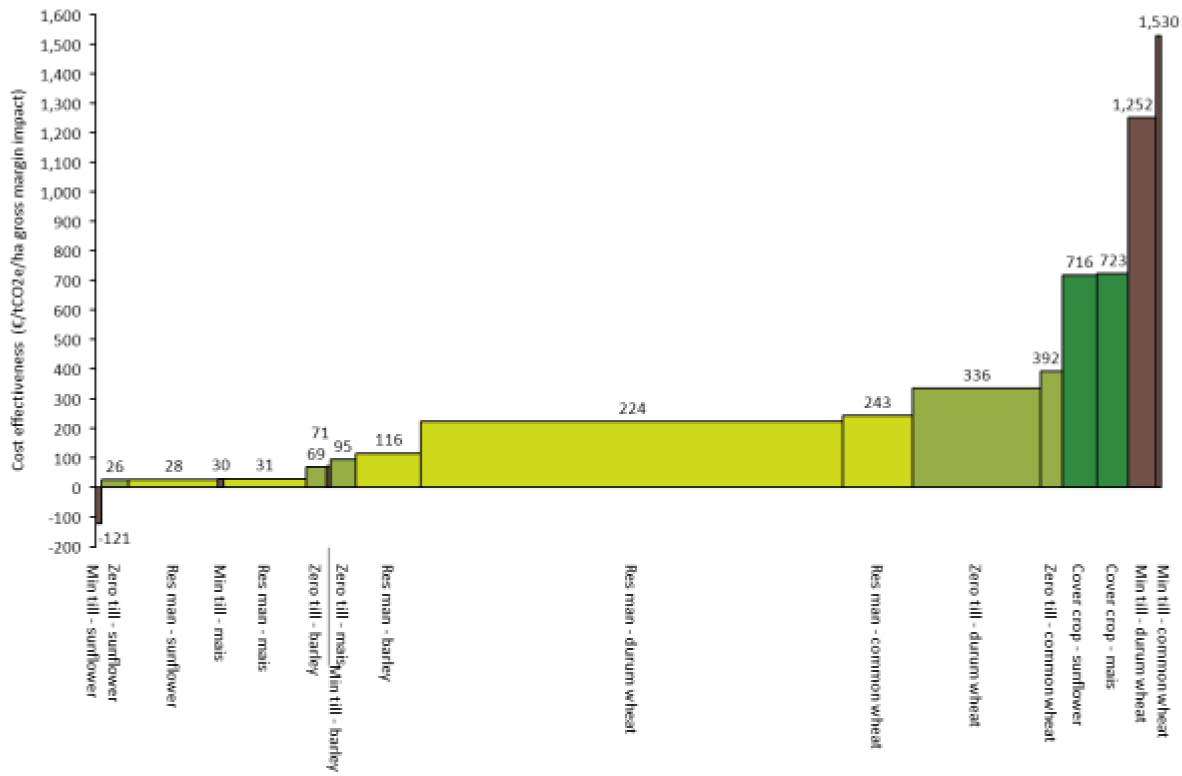

Figure 10 SOC MACC for Tuscany – mean yield impact (all measures and crops)

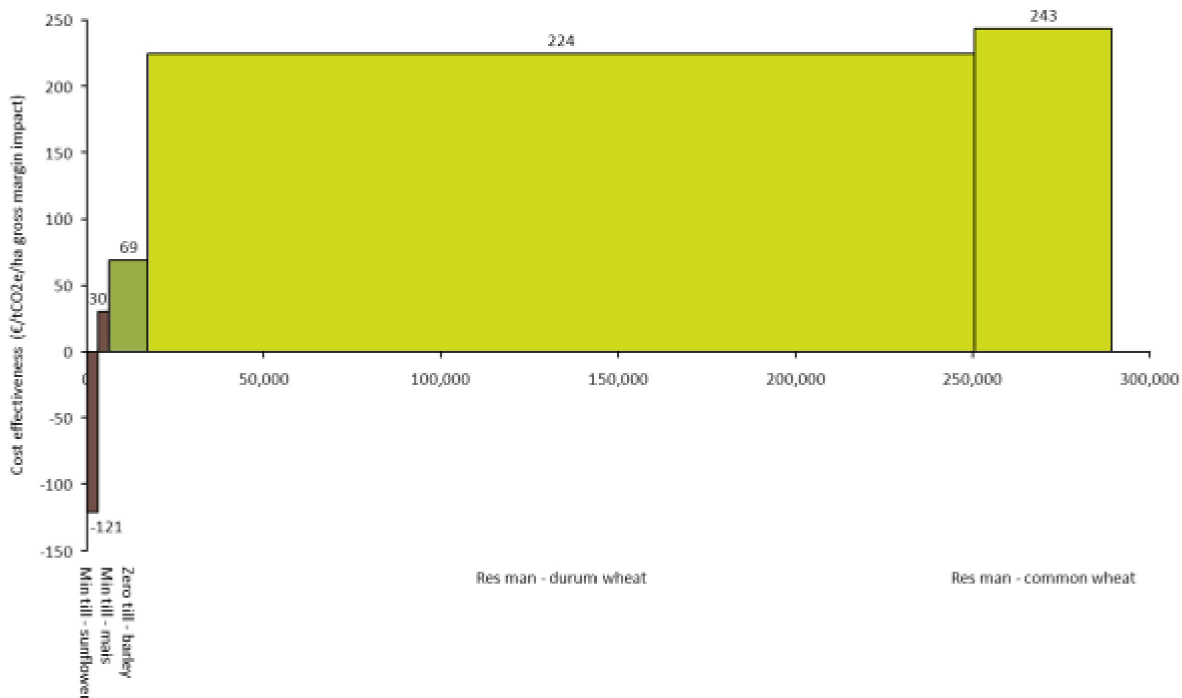

Figure 11 SOC MACC for Tuscany – mean yield impact (best measure for each crop)

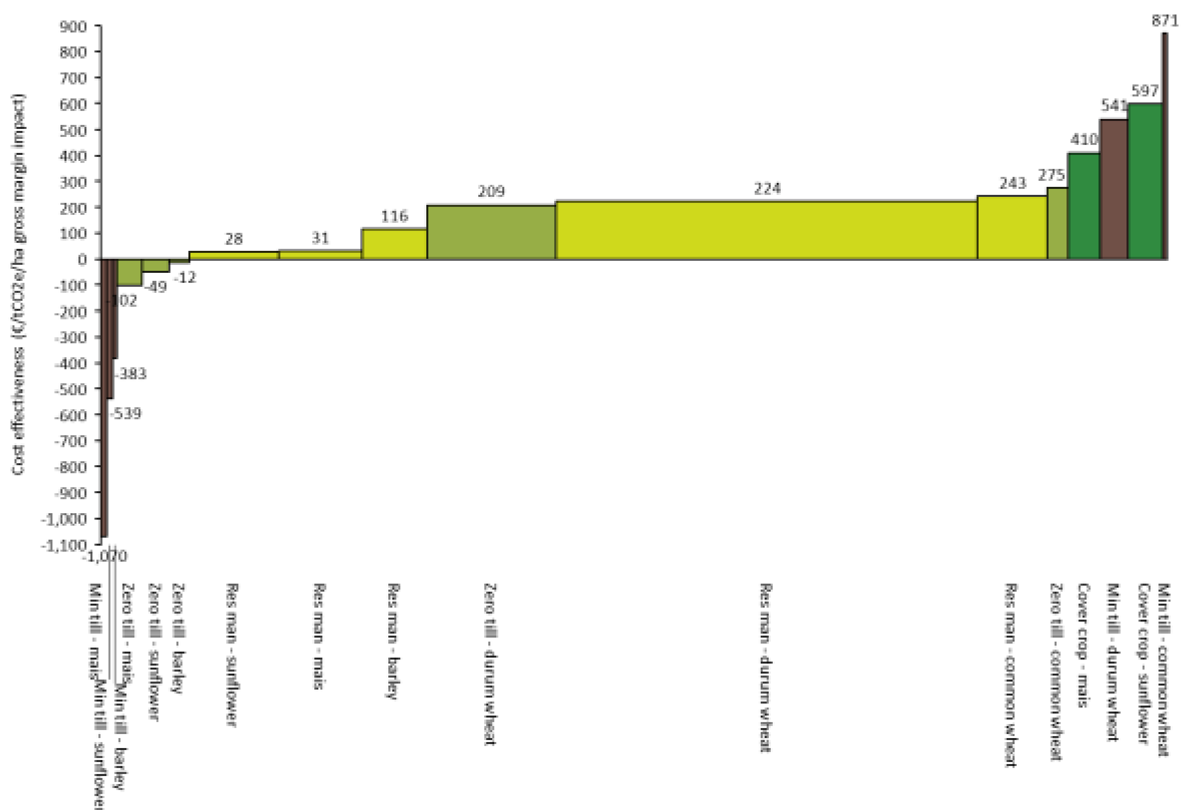

Figure 12 SOC MACC for Tuscany – high yield impact (all measures and crops)

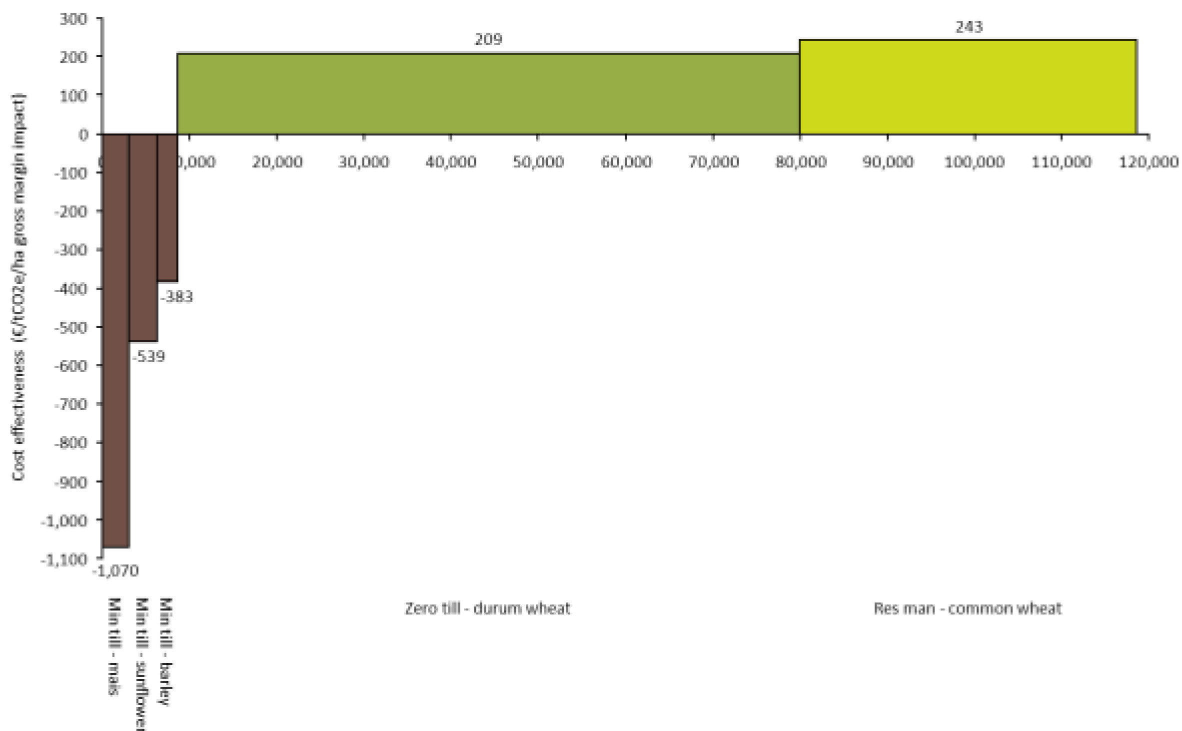

Figure 13 SOC MACC for Tuscany – high yield impact (best measure for each crop)

Poland - Mazovia

For the Polish case study (Figure 14) the most cost-effective measures were legumes (due the cost saving on nutrient inputs); residue management has a small negative cost; cover crops have a high positive cost associated with establishment and a 20% reduction in yield under the 'mean' scenario. Data on different yield impacts were only available for the cover crops measure (for other measures yields were assumed to be constant), the high yield scenario (Figure 16 and Figure 17) were associated with a small improvement in yield relative to the 'mean' impact but still 15% below the yield without the measure. Consequently, there is no change in the ranking of measures between mean and high yields, just a modest change in the cost effectiveness of cover crops.

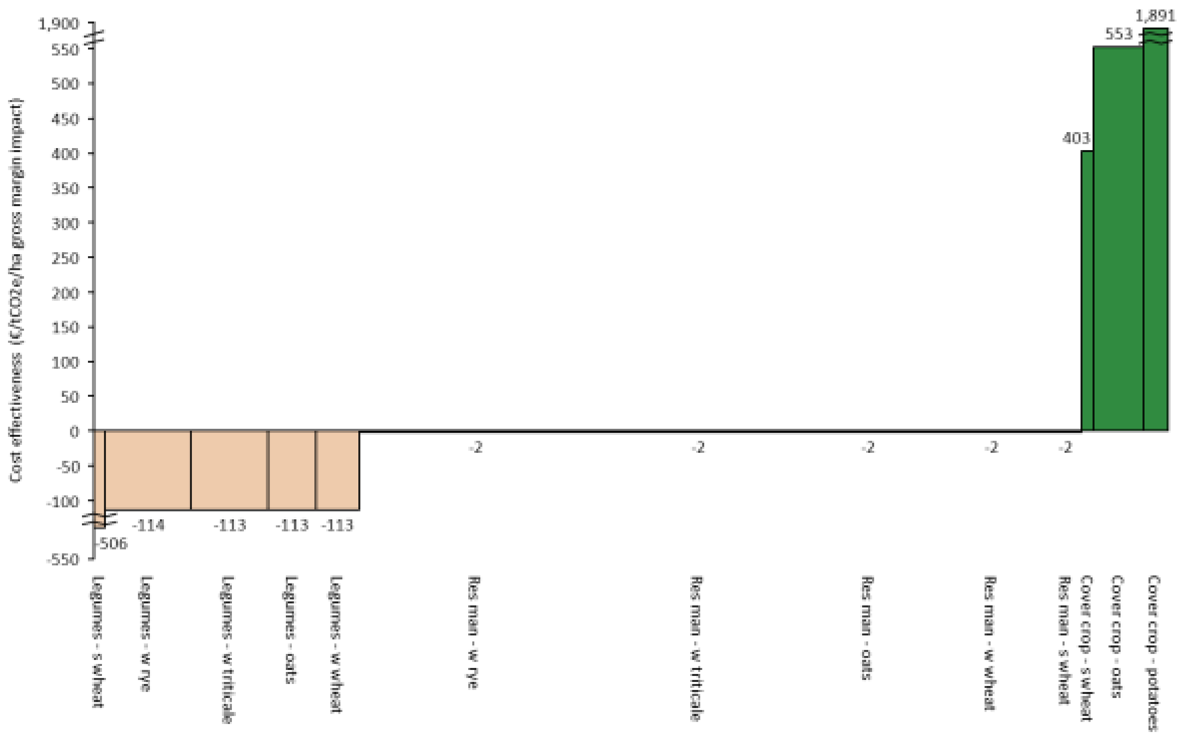

Figure 14 SOC MACC for Poland – mean yield impact (all measures and crops)

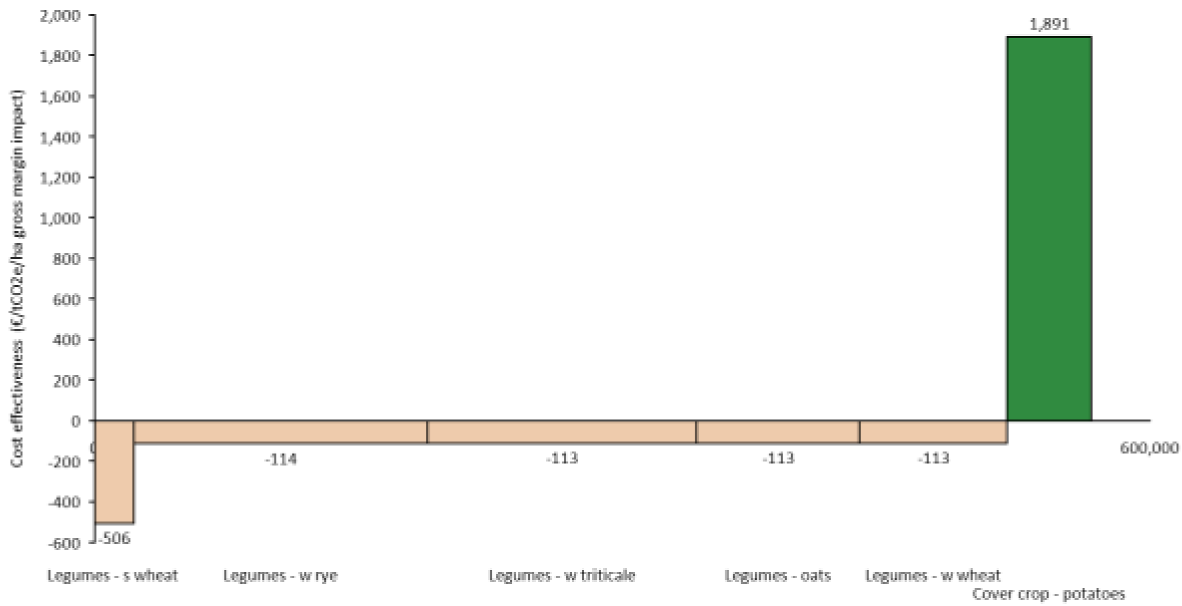

Figure 15 SOC MACC for Poland – mean yield impact (best measure for each crop)

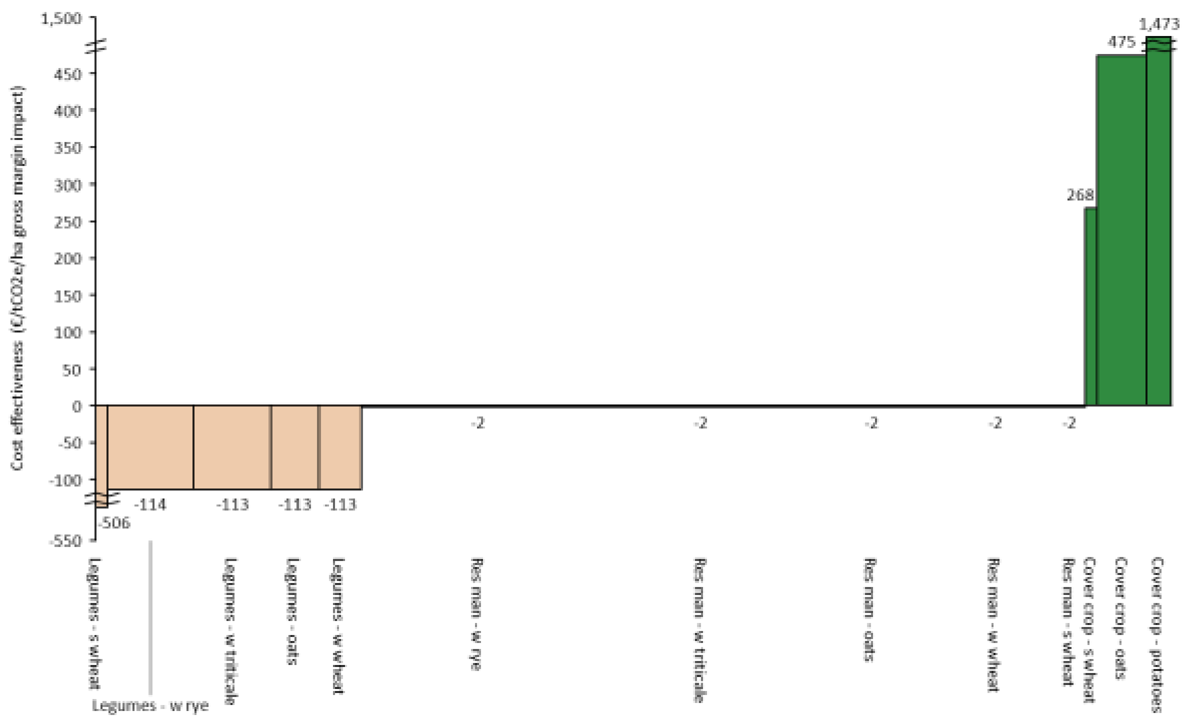

Figure 16 SOC MACC for Poland – high yield impact (all measures and crops)

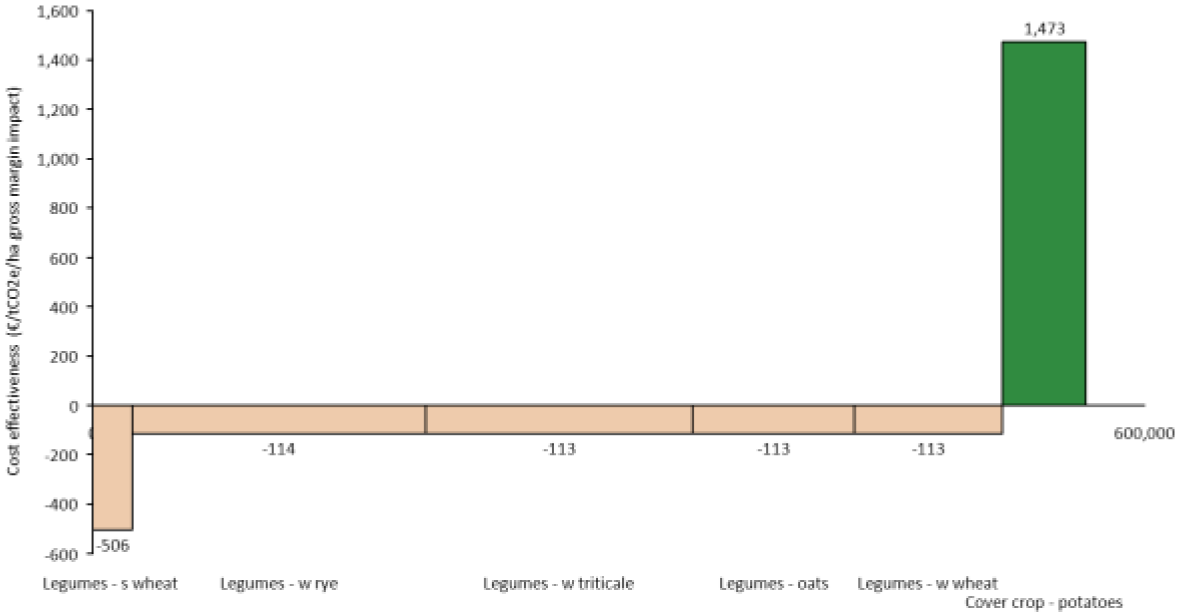

Figure 17 SOC MACC for Poland – high yield impact (best measure for each crop)

Scotland - Eastern

The cost-effectiveness analysis for Scotland indicates a clear ranking of measures with minimum tillage for all crops with the exception of potatoes (both ware and seed) being the only ‘win-win’ measure under the mean yield impact (Figure 18). This is followed by zero tillage, the difference between the two tillage measures being a slightly higher yield for minimum tillage and lower costs, both tillage measure avoid the costs of conventional tillage, but minimum tillage is associated with lower spray costs. Residue management has a positive cost impact due to the loss of revenue from the sale of straw. Cover crops are the least cost-effective due to the establishment costs. The poor cost-effectiveness of potatoes with minimum tillage is due to the decrease in yield of this higher gross margin crop. Figure 19 illustrates that minimum tillage is the most cost-effective measure for all crops with the exception of spring barley for which zero tillage was more cost-effective. SOC increases by approximately 40000 tonnes per annum for this measure across the crops given current cropping levels.

Figure 20 demonstrates the sensitivity of the cost-effectiveness analysis to assumptions about yield impacts. Under the high yield impact assumption, minimum tillage for ware and seed potatoes becomes the most cost-effective measures, under mean yield impact yields fell by 2% compared to the baseline whereas they increase by 10% under the high yield impact. High yield impacts also see zero tillage measures become ‘win-win’ options. Cover crops for spring oats and spring barley are also negative cost measures due to changes in the yield impact. Minimum tillage remains the most cost effective measure across all crops (Figure 21).

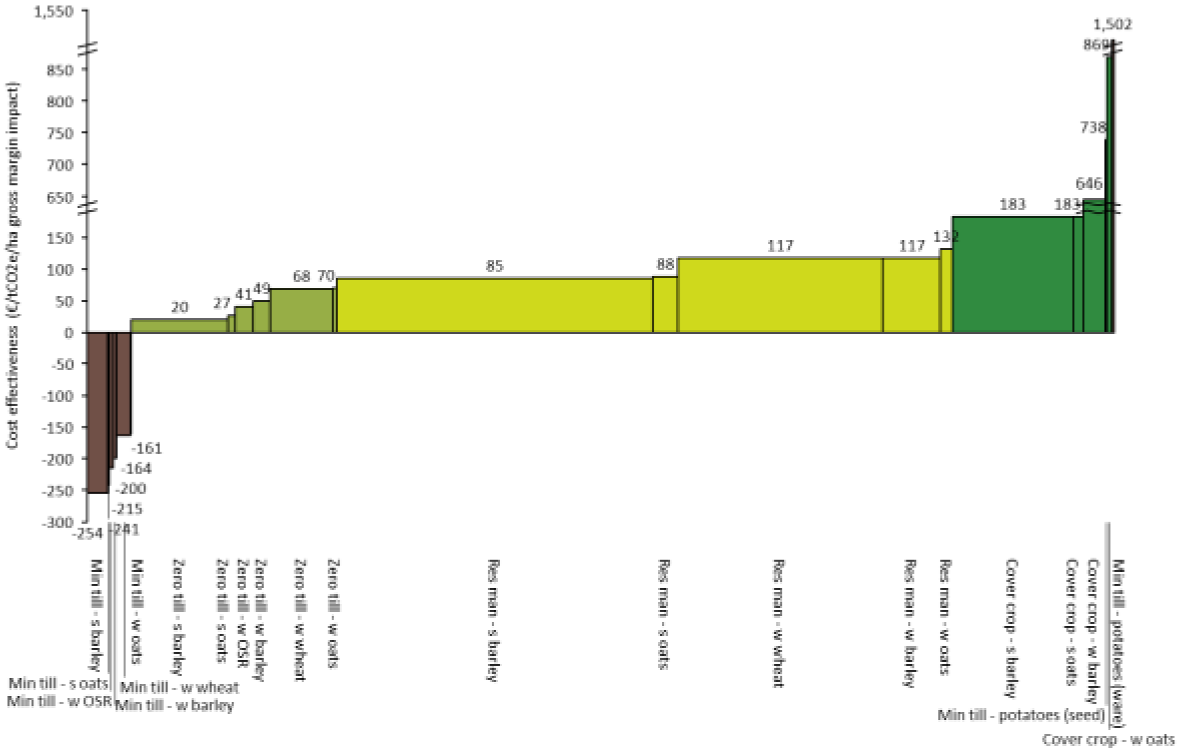

Figure 18 SOC MACC for Scotland – mean yield impact (all measures and crops)

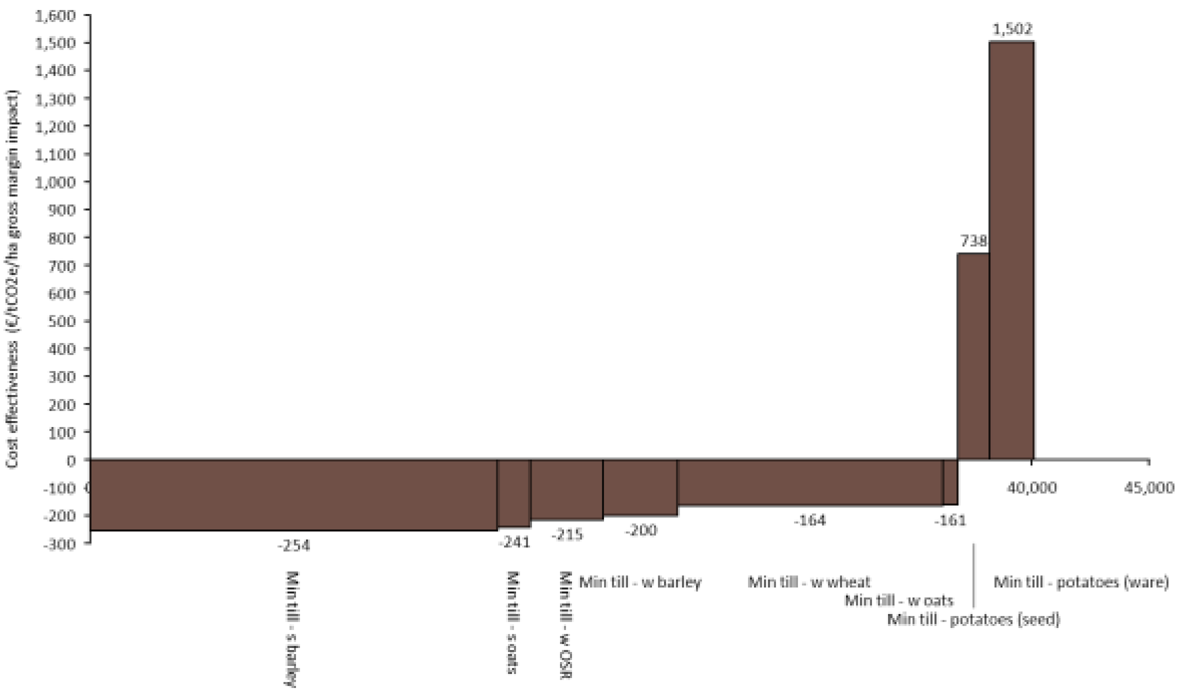

Figure 19 SOC MACC for Scotland – mean yield impact (best measure for each crop)

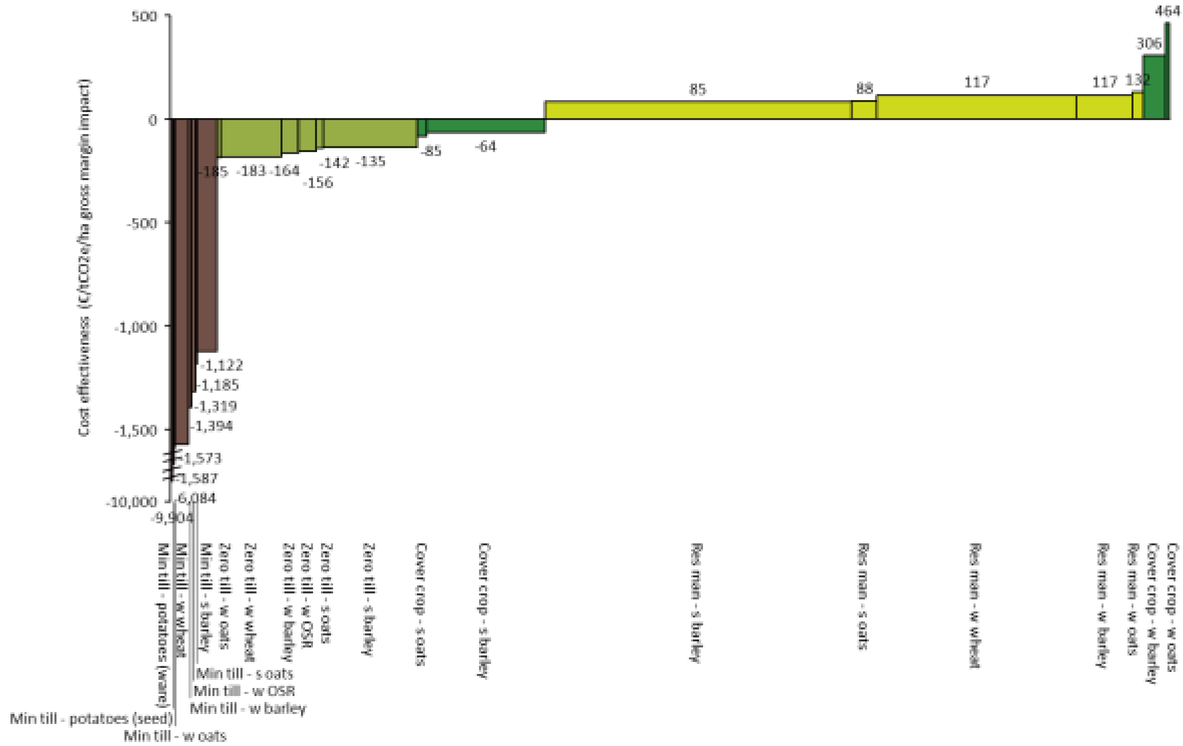

Figure 20 SOC MACC for Scotland – high yield impact (all measures and crops)

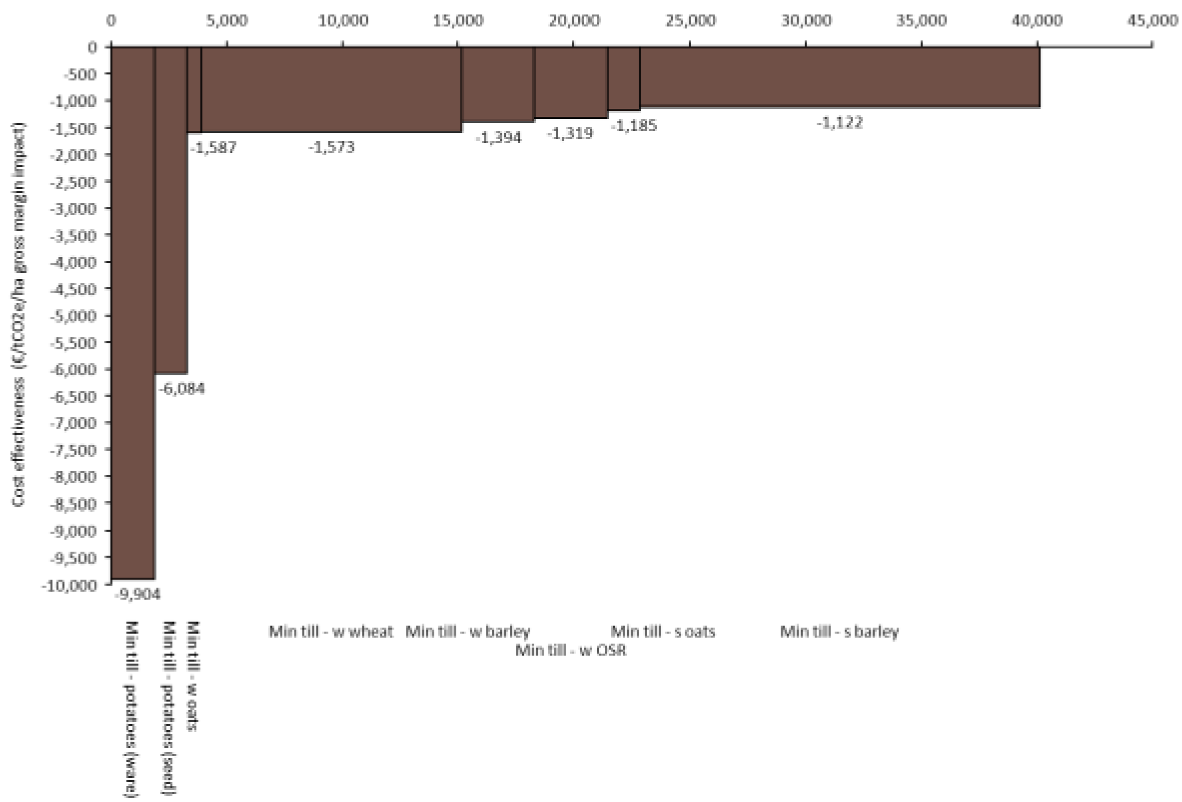

Figure 21 SOC MACC for Scotland – high yield impact (best measure for each crop)

Spain – Andalucía

Figure 22 presents the MACC for the Andalucía case study. This case study had the widest range of SOC measures and crop types include permanent crops (vineyards, olives and almond). A large number of crop and measure combinations were associated with negative costs including minimum tillage, manure, cover crops (maize with both vetch and barley), zero tillage, crop rotations with legumes and optimal fertilisation. Cover crops for the permanent crops had a positive cost and the least cost-effective measure was residue management. The best measures applied to each crop (Figure 23) indicate that SOC could be increased by 717,000 tonnes annually at negative cost.

When the high yield impact is used (Figure 24), cover crops for maize (vetch and barley) become the most cost-effective measures. The ranking of some of the other measures also changes slightly. Although there is no change in the rankings or cost-effectiveness of the cover crops for permanent crops and residue management measures. The reordering of the most cost-effective measures under the high yield impact does mean that if these are adopted then the potential SOC increase falls to 430,000 tonnes at negative cost.

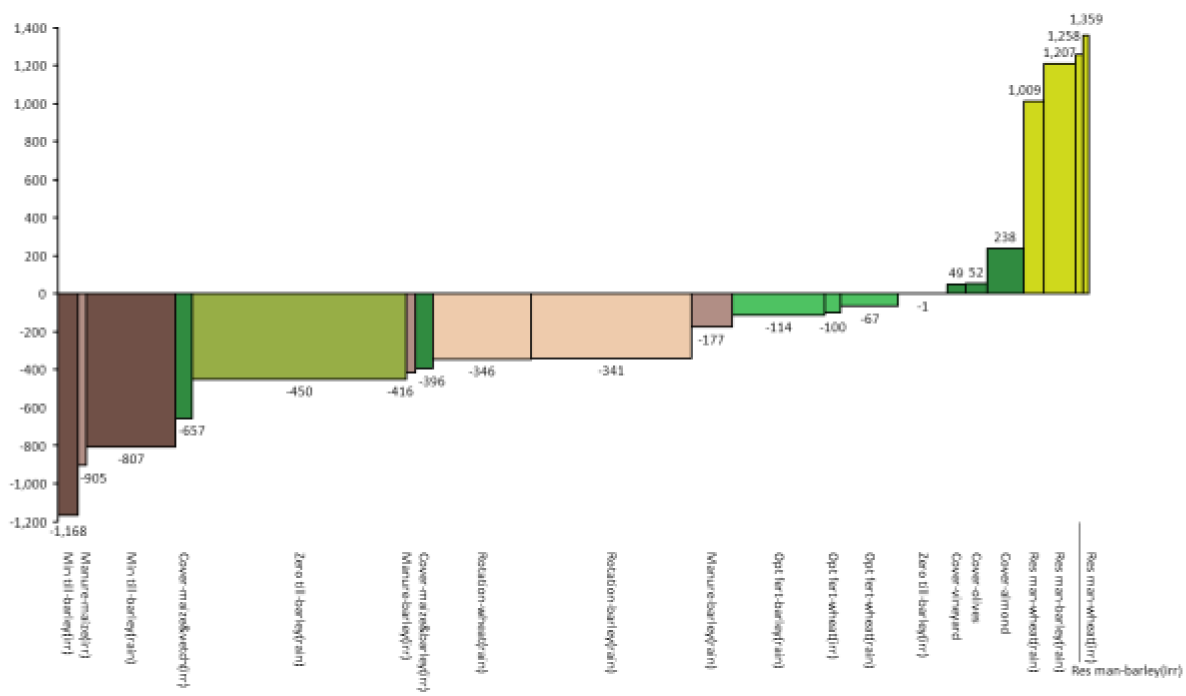

Figure 22 SOC MACC for Spain - mean yield impact (all measures and crops)

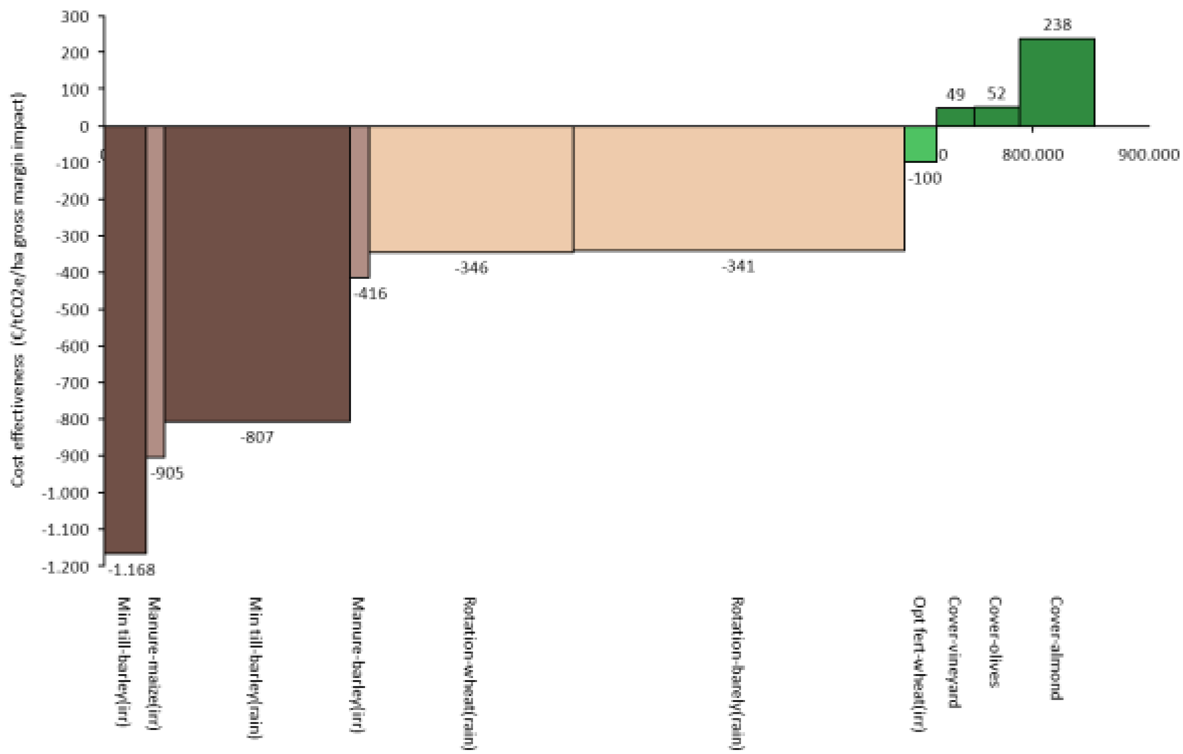

Figure 23 SOC MACC for Spain – mean yield impact (best measure for each crop)

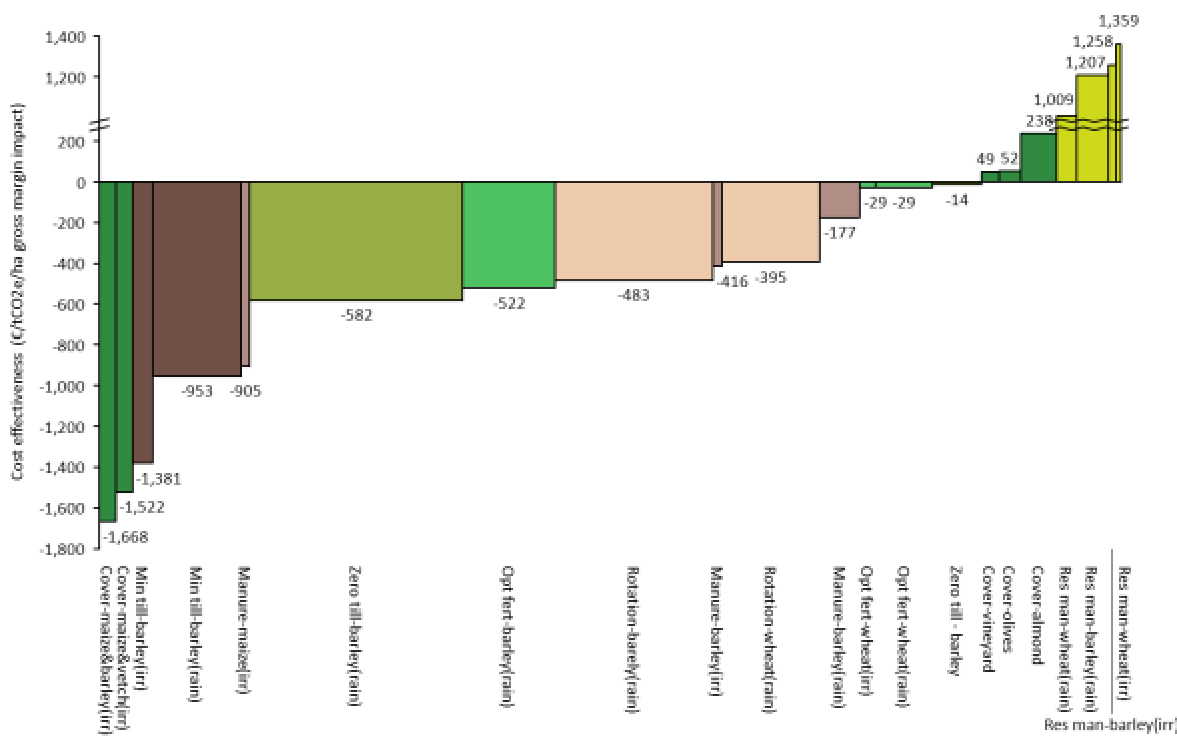

Figure 24 SOC MACC for Spain – high yield impact (all measures and crops)

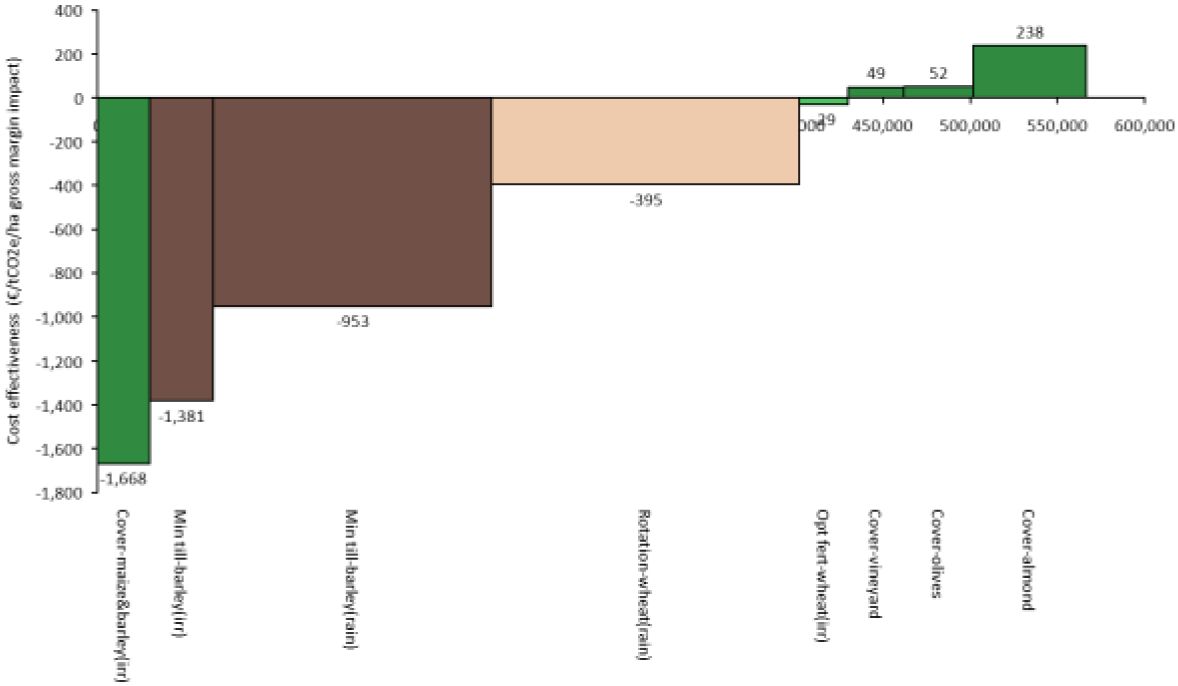

Figure 25 SOC MACC for Spain – high yield impact (best measure for each crop)

Summary

The results of the cost-effectiveness analysis indicate that in each of the case study regions there is potential for the uptake of SOC measures that can produce benefits to farmers in terms of improved gross margins. Whilst the specific measures and crop combinations vary across the case study regions it is possible to group measures into three broad categories:

1. **Reduced input costs**. Measures such as minimum tillage and use of manures are estimated to be highly cost-effective even where modest reductions in yield occur because of the potential to reduce inputs costs. These input costs include the fuel and time required for cultivation relative to conventional tillage (minimum tillage) and reduced mineral fertiliser costs (manures). Zero tillage performs less well as there is a need for increased spraying. The inclusion of legumes in rotations also appears to be cost-effective due to the reduced need for mineral fertiliser input. However, this highlights a limitation of the analysis in that it does not consider the impacts over the course of a rotation.
2. **Loss of revenue from by-product**. Residue management has a high potential for SOC increase in most case study regions but this could only be achieved at a loss of gross margin due to foregone revenue from selling straw as a by-product.
3. **Increased input costs**. Under the mean yield impact assumption cover crops were estimated to result in a large reduction in gross margin due to the additional costs of seeds and cultivation. However, the cost-effectiveness of this measure was highly sensitive to the impact on yield, and under the high yield impacts the cost-effectiveness improved for some crops in some regions. This highlights the potential role for good agronomic advice in encouraging uptake to ensure that the benefits of SOC measures can be fully realised.

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Appendix 1 Cost-effectiveness tables

Denmark

Measure	Crop	SOC impact (tCO_2e/yr total area)	SOC impact (tCO_2e/yr per ha)	GHG impact (tCO_2e/yr total area)	Cost effectiveness (SOC, €GM/tCO2e)			Cost effectiveness (GHG, €GM/tCO2e)		
					Mean yield impact	Low yield impact	High yield impact	Mean yield impact	Low yield impact	High yield impact
Cover crop/ catch crop	Winter wheat	474229	0.88	528119	139	328	-240	124	294	-215
	Spring wheat	24969	0.88	27807	139	275	-134	124	247	-120
	Winter barley	95784	0.88	106668	139	297	-178	124	267	-160
	Spring barley	508782	0.88	566598	139	283	-150	124	254	-135
Displacing winter for spring crop	Spring wheat	24969	0.88	27807	668	805	396	600	722	355
	Spring barley	508782	0.88	566598	231	375	-58	207	337	-52
Minimum/non-inversion tillage	Winter wheat	80835	0.15	113168	-78	810	-1410	-56	579	-1007
	Spring wheat	4256	0.15	5959	-140	500	-1100	-100	357	-785
	Winter barley	16327	0.15	22857	-114	630	-1230	-81	450	-879
	Spring barley	86724	0.15	121414	-131	547	-1147	-93	390	-819
Residue management	Winter wheat	1234074	2.29	1158629	45	45	45	48	48	48
	Spring wheat	64976	2.29	61004	45	45	45	48	48	48
	Winter barley	249255	2.29	234017	41	41	41	44	44	44
	Spring barley	1323989	2.29	1243046	38	38	38	41	41	41

Hungary

Measure	Crop	SOC impact (tCO2e/yr total area)	SOC impact (tCO2e/yr per ha)	GHG impact (tCO2e/yr total area)	Cost effectiveness (SOC, €GM/tCO2e)			Cost effectiveness (GHG, €GM/tCO2e)		
					Mean yield impact	Low yield impact	High yield impact	Mean yield impact	Low yield impact	High yield impact
Green manure	Winter wheat	41202	0.88	45884	192	259	58	172	232	52
	Maize	46863	0.88	52189	192	296	-16	172	266	-15
	Winter barley	9578	0.88	10667	192	249	77	172	224	69
	Sunflower	31011	0.88	34535	192	286	3	172	257	3
	Rapeseed	9299	0.88	10355	192	282	11	172	254	10
Organic manure (stall or slurry)	Winter wheat	10066	0.215	9224	-1552	-730	-2511	-1694	-796	-2741
	Maize	11450	0.215	10491	-1204	-181	-1886	-1314	-198	-2059
	Winter barley	2340	0.215	2144	-181	-181	-181	-198	-198	-198
	Sunflower	7577	0.215	6942	-181	-181	-181	-198	-198	-198
	Rapeseed	2272	0.215	2082	-181	-181	-181	-198	-198	-198
Minimum/ conservation tillage	Winter wheat	7023	0.15	9832	-340	-26	-812	-243	-18	-580
	Maize	7988	0.15	11183	-296	192	-1030	-212	137	-735
	Winter barley	1633	0.15	2286	-351	-81	-756	-251	-58	-540
	Sunflower	5286	0.15	7400	-308	135	-972	-220	96	-694
	Rapeseed	1585	0.15	2219	-312	113	-950	-223	80	-679
Residue management	Winter wheat	107218	2.29	100663	28	28	28	29	29	29
	Winter barley	24925	2.29	23402	30	30	30	32	32	32
	Rapeseed	24197	2.29	22718	72	72	72	77	77	77
Legumes	Winter wheat	39329	0.84	39329	-113	-113	-113	-113	-113	-113
	Maize	44733	0.84	44733	-113	-113	-113	-113	-113	-113
	Sunflower	29601	0.84	29601	-113	-113	-113	-113	-113	-113
	Rapeseed	8876	0.84	8876	-113	-113	-113	-113	-113	-113

Italy

Measure	Crop	SOC impact (tCO2e/yr total area)	SOC impact (tCO2e/yr per ha)	GHG impact (tCO2e/yr total area)	Cost effectiveness (SOC, €GM/tCO2e)			Cost effectiveness (GHG, €GM/tCO2e)		
					Mean yield impact	Low yield impact	High yield impact	Mean yield impact	Low yield impact	High yield impact
Cover crop	Sunflower	19059	0.88	21225	716.29	775.69	597.48	643.20	696.54	536.51
	Maize	17686	0.88	19696	722.63	878.90	410.09	648.89	789.22	368.24
Zero Tillage	Durum wheat	71338	0.7	29554	335.69	526.23	208.67	810.29	1270.21	503.68
	Common wheat	11813	0.7	4894	392.48	569.09	274.74	947.36	1373.65	663.16
	Maize	14068	0.7	5828	94.68	389.36	-101.78	228.53	939.84	-245.67
	Sunflower	15161	0.7	6281	25.82	137.84	-48.86	62.32	332.72	-117.94
	Barley	11024	0.7	4567	68.86	190.55	-12.27	166.20	459.94	-29.62
Minimum tillage	Durum wheat	15287	0.15	21401	1252.06	1726.29	540.72	894.33	1233.06	386.23
	Common wheat	2531	0.15	3544	1530.05	1969.61	870.71	1092.90	1406.87	621.94
	Maize	3015	0.15	4221	30.13	763.56	-1070.02	21.52	545.40	-764.30
	Sunflower	3249	0.15	4548	-120.74	158.07	-538.95	-86.24	112.91	-384.96
	Barley	2362	0.15	3307	71.08	373.96	-383.24	50.77	267.11	-273.74
Residue management	Durum wheat	233377	2.29	219110	224.42	224.42	224.42	239.04	239.04	239.04
	Common wheat	38644	2.29	36281	243.20	243.20	243.20	259.03	259.03	259.03
	Maize	46024	2.29	43210	30.53	30.53	30.53	32.52	32.52	32.52
	Sunflower	49598	2.29	46566	28.09	28.09	28.09	29.92	29.92	29.92
	Barley	36066	2.29	33861	116.16	116.16	116.16	123.72	123.72	123.72

Poland

Measure	Crop	SOC impact (tCO2e/yr total area)	SOC impact (tCO2e/yr per ha)	GHG impact (tCO2e/yr total area)	Cost effectiveness (SOC, €GM/tCO2e)			Cost effectiveness (GHG, €GM/tCO2e)		
					Mean yield impact	Low yield impact	High yield impact	Mean yield impact	Low yield impact	High yield impact
Cover crop	Oat	96943	0.88	107960	552.84	630.97	474.72	496.43	566.58	426.28
	Wheat (spring)	23687	0.88	26379	402.61	536.93	268.30	361.53	482.14	240.92
	Potatoes	47701	0.88	53122	1890.80	2308.24	1473.35	1697.86	2072.70	1323.01
Residue management	Rye (winter)	455999	2.29	428121	-2.38	-2.38	-2.38	-2.53	-2.53	-2.53
	Triticale (winter)	415111	2.29	389733	-2.18	-2.18	-2.18	-2.33	-2.33	-2.33
	Oat	252273	2.29	236850	-2.18	-2.18	-2.18	-2.33	-2.33	-2.33
	Wheat (winter)	229456	2.29	215428	-2.18	-2.18	-2.18	-2.33	-2.33	-2.33
	Wheat (spring)	61640	2.29	57872	-2.18	-2.18	-2.18	-2.33	-2.33	-2.33
Legumes	Rye (winter)	167266	0.84	167266	-113.63	-113.63	-113.63	-113.63	-113.63	-113.63
	Triticale (winter)	152268	0.84	152268	-113.10	-113.10	-113.10	-113.10	-113.10	-113.10
	Oat	92537	0.84	92537	-113.10	-113.10	-113.10	-113.10	-113.10	-113.10
	Wheat (winter)	84167	0.84	84167	-113.10	-113.10	-113.10	-113.10	-113.10	-113.10
	Wheat (spring)	22610	0.84	22610	-505.95	-505.95	-505.95	-505.95	-505.95	-505.95

Scotland

Measure	Crop	SOC impact (tCO2e/yr total area)	SOC impact (tCO2e/yr per ha)	GHG impact (tCO2e/yr total area)	Cost effectiveness (SOC, €GM/tCO2e)			Cost effectiveness (GHG, €GM/tCO2e)		
					Mean yield impact	Low yield impact	High yield impact	Mean yield impact	Low yield impact	High yield impact
Cover crop	Winter barley	18426	0.88	20520	646	815	306	580	732	275
	Spring barley	101594	0.88	113139	183	306	-64	164	275	-57
	Winter oats	3834	0.88	4270	869	1072	464	780	962	417
	Spring oats	8184	0.88	9114	183	317	-85	164	285	-76
Zero tillage	Winter wheat	52484	0.70	21743	68	446	-183	165	1076	-442
	Winter barley	14657	0.70	6072	49	369	-164	119	891	-396
	Spring barley	80814	0.70	33480	20	252	-135	48	609	-326
	Winter oats	3050	0.70	1264	70	452	-185	169	1090	-446
	Spring oats	6510	0.70	2697	27	279	-142	64	674	-342
	Winter oilseed rape	14521	0.70	6016	41	337	-156	99	813	-377
Minimum tillage	Winter wheat	11247	0.15	15745	-164	776	-1573	-117	554	-1123
	Winter barley	3141	0.15	4397	-200	597	-1394	-143	426	-996
	Spring barley	17317	0.15	24244	-254	325	-1122	-181	232	-801
	Winter oats	654	0.15	915	-161	790	-1587	-115	564	-1134
	Spring oats	1395	0.15	1953	-241	387	-1185	-172	277	-846
	winter oilseed rape	3112	0.15	4356	-215	521	-1319	-153	372	-942
	Potatoes (ware)	1896	0.15	2654	1502	9107	-9904	1073	6505	-7074
	Potatoes (seed)	1367	0.15	1914	738	5287	-6084	527	3776	-4346
Residue management	Winter wheat	171697	2.29	161201	117	117	117	125	125	125
	Winter barley	47950	2.29	45019	117	117	117	125	125	125
	Spring barley	264376	2.29	248213	85	85	85	90	90	90
	Winter oats	9978	2.29	9368	132	132	132	140	140	140
	Spring oats	21297	2.29	19995	88	88	88	94	94	94

Spain

Measure	Crop	SOC impact (tCO2e/yr total area)	SOC impact (tCO2e/yr per ha)	GHG impact (tCO2e/yr total area)	Cost effectiveness (SOC, €GM/tCO2e)			Cost effectiveness (GHG, €GM/tCO2e)		
					Mean yield impact	Low yield impact				
Cover crop	Maize (irrigated) – vetch	29838	0.42	28559	-657	-172	-1522	-686	-180	-1591
	Maize (irrigated) – barley	29838	0.42	28559	-396	678	-1668	-414	708	-1743
	Almond (rainfed)	64924	1.10	63862	238	238	238	242	242	242
	Vineyard (rainfed)	31970	1.10	31447	49	49	49	50	50	50
	Olives (rainfed)	39377	1.10	38732	52	52	52	53	53	53
Zero tillage	Barley (rainfed)	383381	1.13	376595	-450	-209	-582	-458	-213	-592
	Barley (all)	87915	1.13	86359	-1	12	-14	-1	12	-14
Minimum/ conservation tillage	Barley (rainfed)	159459	0.47	159459	-807	-710	-953	-807	-710	-953
	Barley (irrigated)	36566	0.47	36566	-1168	-1027	-1381	-1168	-1027	-1381
Residue management	Wheat (rainfed)	35630	0.17	39821	1009	1009	1009	903	903	903
	Wheat (irrigated)	9782	0.17	10933	1359	1359	1359	1216	1216	1216
	Barley (rainfed)	57677	0.17	64462	1207	1207	1207	1080	1080	1080
	Barley (irrigated)	13226	0.17	14782	1258	1258	1258	1126	1126	1126
Fertilization with animal manures	Barley (rainfed)	72944	0.22	66837	-177	-177	-177	-193	-193	-193
	Barley (irrigated)	16727	0.22	15327	-416	-416	-416	-454	-454	-454
	Maize (irrigated)	15274	0.22	13995	-905	-905	-905	-988	-988	-988
Optimized fertilization	Wheat (rainfed)	102697	0.49	113596	-67	-29	-29	-60	-26	-26
	Wheat (irrigated)	28195	0.49	31187	-100	-29	-29	-90	-26	-26
	Barley (rainfed)	166245	0.49	160138	-114	379	-522	-118	394	-542
Crop rotations (with legumes)	Wheat (rainfed)	176052	0.84	176052	-346	-291	-395	-346	-291	-395
	Barley (rainfed)	284991	0.84	284991	-341	-199	-483	-341	-199	-483

Appendix 2 Barriers to uptake of measures

In the stakeholder workshops undertaken as part of task 5.2, participants were presented with the MACC figures from the cost-effectiveness analysis. An important part of the discussion was the consideration of the barriers to the uptake of the SOC measures. These outcomes are outlined below. For full details we refer you to the deliverable 5.2 report 'Overview of socio-economic influences on crop and soil management systems'. Here we consider only those measures for which cost-effectiveness was estimated.

Denmark

Zero and minimum tillage - In this workshop it emerged that zero- or reduced tillage is regarded as being technically difficult and therefore only attractive for the very skilled or dedicated farmers. Farmers generally felt they had a lack of practical skills to implement this measure, with the difficulties exacerbated by the cold climate. Specific problems identified related to germination/crop growth; perennial weed problems; and a lack of appropriate existing technology to control weeds on organic farms. The main social barrier related to the aesthetic value of fields with zero or minimum tillage regarded as looking 'messy'. The economic barriers related to an increased risk of crop failure and the need to change crop types in order to maintain yields. The two main barriers of these practices were identified as a risk of crop failure and perennial weed failures.

Catch crops are mandatory in Denmark and are unpopular. The participants reported that the benefits of catch crops to farmers are unclear and that there is a lack of scientific knowledge and communication to farmers. A number of technical difficulties with cover crops were reported, including a lack of time after harvest to accommodate catch crops and difficulties in successful establishment due to germination problems. Also catch crops were considered to prevent efficient mechanical weed control and to allow less flexibility in choosing winter crops vs. spring-sown crops. Economic barriers reported for catch crops related to potentially high crop replacement costs (winter wheat replaced with spring barley); time consuming (involving extra field operations); and costly to establish. The two main barriers to uptake identified were uncertainty about the benefits of catch crops and less flexibility in the choice of crops.

Residue management – No technical or social barriers were identified as preventing the uptake of residue management and in fact it was suggested that regulations have helped to encourage the implementation of this practice. The only barrier identified was an economic one related to loss of income from straw.

Adding legumes – Growing catch crops in Denmark is mandatory, but legumes are not accepted as one of the mandatory catch crops. As a result it is considered costly to grow legumes as a catch crop in addition to those required by legislation. Also concerns were expressed about the potential risk of crop failure when using catch crops.

Long/short grass rotation – No barriers to implementation of long/short grass rotation were identified on dairy farms, however, on non-dairy farms there was concern about the availability of livestock to graze on the grass/sward and also the lack of biogas plants for using grass as an input. Consequently, on non-dairy farms grass rotations were not considered an-effective option.

Hungary

Zero and reduced tillage. The practice of zero or reduced tillage is limited in the region due to a lack of necessary equipment, particularly for the small farms that, due to a lack of financial resources, are not in a position to acquire the machinery required for more advanced soil carbon management. Also a more widespread uptake of conservation and zero-tillage practices is limited due to knowledge barriers. Amongst the less educated farmers there is both a lack of appropriate knowledge about soils in general and at the same time a strong attachment to “traditional” methods, with a limited openness towards new approaches.

Catch/cover crops. There is a limited use of green manure crops due to time constraints; harvesting is considered more important than establishing green manure crops. Furthermore, catch crops and cover crops are rarely used, as they are not considered a traditional practice, although in some agri-environment measures, the crop rotation requirement includes legumes.

Residue management. One reason for limited uptake of residue management practices is that the straw can have a high economic value. For example, local mushroom producers will often pay a very high price for straw and even undertake the baling themselves. Also a misinterpretation of the bioenergy/bioeconomy concept has led to an overutilization of soil organic carbon sources available on the field (e.g. straw and crop residues). One agronomic barrier identified is the difficulty of utilizing crop residues under certain/extreme weather conditions.

Adding legumes. For the sandy soils grown in the region, the type of crops that can be grown are limited and are often not suitable for legumes. Furthermore, legumes are often not profitable in the region and grown only on an occasional basis.

Nutrient management. Some of the advisory services on nutrient management are out of date and there are often contradictions between specialists interested in nutrient management and those with an interest in soil protection. Furthermore manure application is considered administratively burdensome due to (over) regulation.

Italy

Minimum/zero tillage. In the Italian case study workshop minimum/zero tillage practices generated the most comments in relation to barriers to implementation. A reported technical barrier affecting implementation of this practice related to increased uncertainties in both the quality and quantity of crop yields. It was suggested that water and nutrient competition as the result of increased weed population would affect yields. Also, with regards zero tillage there were additional concerns about meeting market standards for product health and quality. It was also suggested that farmers may lack the required machinery to undertake this practice and therefore would be deterred by the need for new investments. Furthermore, these measures would increase organizational /logistical complexity and would require changes in the management system. As with any new practice farmers are concerned that it will take time to integrate the practice into the existing farm management system, which initially could result in a loss of both yields and income.

Farmers in the region can have difficulty in accepting any practice that is “outside” their knowledge and experience and this is a particular barrier for the older farmers. Currently, there appears to be a lack of farmer awareness about minimum tillage practices due to insufficient dissemination and communication about these practices and their benefits. In particular there is a lack of practical real-life examples and inadequate specific regional agricultural services to provide this information and train farmers. The main economic barriers reported relate to increased income uncertainties and a concern that the practice may result in higher costs for weeding and for new machinery investment.

Residue management. The only potential barrier to adopting residue management related to the need to sometimes add mineral fertiliser before incorporation of the residues. In such situations, this practice would result in higher costs.

Green manure. The main barrier to applying green manure is economic. The practice would result in higher costs from the management of a crop that does not provide any economic profit. Any technical- agronomic advantage is only realised in the long-term.

Catch crops. This measure is considered to increase operational complexity and result in more agronomic difficulties for managing crop rotations and higher costs. It is not a traditional practice in the region and there is currently a lack of farmer awareness about the practice and insufficient dissemination/communication of its benefits.

Poland

Cover crops. A number of barriers were identified for cover crops including the cost of seeds and cultivation (e.g. fuel) and the fact that they add complication to farm practices. The need to sell the resulting crop is also a problem, as previously these may have been used as livestock feed on mixed farms, specialisation means that this is no longer an option for use. Water availability is also a constraint with the problem of drought during the sowing period and the fear that the crop will reduce soil moisture available for following crops.

Legumes. This measure saw similar barriers to cover crops including the cost of seed and cultivation, and also the move away from mixed farming has reduced on-farm demand for animal feed.

Residue management. No barriers were identified.

Scotland

Cover crops. The main barrier to cover crops in Scotland was the late harvest times of the preceding crop meaning that there is often little time available for establishment of the cover crop. For farmers targeting the high value malting market for spring barley the need to ensure low nitrogen content in the grain was a further barrier to uptake as cover crops may make it difficult to control nutrient inputs.

Zero/minimum tillage. There were no specific barriers identified for zero or minimum tillage, and the reduced time required for minimum tillage was seen as attractive for farmers. However, uptake of these measures remains low.

Residue management. Straw is a valuable by product with a market in the livestock sector. The relatively low current price of potash was also important as this further reduces the incentive for straw incorporation despite this being seen as beneficial for workability. This highlights the importance of balancing input and output values in decision making.

Spain

Cover crops. A potential barrier to the uptake of cover crops in rainfed systems in Spain is a concern about decreases in soil moisture and water and nutrient competition between the crops. Also this practice might increase costs due to the requirements for maintenance and management of the cover crop. As a social barrier, it was suggested that this practice currently has a low acceptance amongst farmers who would need to see it adopted more extensively in the surrounding areas before considering uptake. This reluctance highlights to need for farmer training adapted to regional conditions.

Zero/minimum tillage. Barriers to implementation suggested by participants related to concerns about additional costs for purchasing new machinery and the costs from additional weed control. It is particularly difficult for the small sized farms to absorb such costs and there are many smallholders in the region with less than 5 ha of olives groves. Also, as there is a strong tradition of conventional tillage practices in the region and an elderly farming population, there is low acceptance of these new practices, particularly as there is little evidence of other farmers in the surrounding farms adopting these practices.

Residue management. Potential barriers to adopting residue management related to concerns about additional costs for new equipment and increased labour costs as result of additional operations, such as removing and grinding crop residues. Currently, farmers practice stubble burning and therefore do not recognise the need for adopting such a practice. Also the demand for straw for animal feed means that residue management practices could result in income losses.

Manure fertilisation. Barriers identified in relation to this practice relate to the restrictive legislative requirements for manure management treatment and transportation. Also the amount of manure available is limited and sometimes transportation distances are long. Furthermore, there are concerns about increased costs from the operations required to apply and manage the manure. There is a low acceptance of this practice by farmers due to potential impacts on neighbouring farmers and issues with odour for farmers located near to urban or populated areas.

Optimized fertilisation. Barriers to uptake relate to the costs involved in introducing the practices. For example costs involved in new infrastructure, such as fertigation and monitoring systems, in addition to the costs of soil analysis. In general, farmers in the area are risk adverse in relation to fertiliser issues and therefore there is a need for training and capacity building.

Crop rotation (with legumes). This was not considered an appropriate practice in arid areas with precipitation of less than 400 mm/year. Economic barriers identified as potentially hampering uptake were concerns about increased costs due to more management and input requirements and the difficulties in selling legumes due to the lack of an existing market and competition with soybean imports. Cultural barriers also exist as the practice has been discredited in the past. Furthermore, there is uncertainty and a lack of experimental evidence on the N_2O net emissions from growing legumes.