Sustainable farm Management Aimed at Reducing Threats to SOILs under climate chang

Deliverable 2.1 Report describing the practices and measures in European farming systems to manage soil organic matter

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Deliverable 2.1

Report describing the practices and measures in European farming systems to manage soil organic matter.

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Summary

This Deliverable 2.1 is part of Work Package (WP) 2 on "Current and future crop and soil management systems in Europe" and defines key crops and soil management practices among the different European countries as they affect SOC flows and stocks and their applicability in various farming systems and agro-ecological zones in Europe.

The practices examined indicate a range of mitigation potentials, and trade-offs in terms of costs, technical or societal issues, but also the possibility of positive side effects such as wider environmental benefits, for example to biodiversity.

For the cropland practices detailed, using catch crops and reducing fallow periods was shown to be an entirely positive option, increasing soil C storage and reducing erosion, and also reducing N_2O emissions and N leaching, while reducing the demand for mineral fertiliser. Of the tillage options, reduced or conservation tillage was argued to be preferable to zero tillage for most conditions, as it has benefits in terms of increased soil C storage, but with less chance of this being offset by increases in N_2O emissions, and is also less likely to reduce crop yields. Reduced tillage can also be practiced in combination with residue incorporation for added benefits. The benefits of set aside depend on its knock-on effects on land which remains in production, as savings in terms of increased C storage and reduced GHG emissions may be offset if other land is more intensively managed or brought into production to make up for the loss of productivity. Expanding field margins and other partial set aside options may be a good compromise, as the practice also has benefits in terms of biodiversity and reduced N leaching. While less intensive agriculture is a positive step for the environment, it reduces the financial viability of individual farms and therefore, while there is agricultural land surplus to food requirements, growing bio-energy crops on this land may be the best solution.

Fertilizer inputs are one of the main driving factors of soil GHG emissions, especially N_2O, and therefore any measures which reduce these have potentially high mitigation value. Selecting fertiliser types and using precisions farming techniques to ensure inputs are matched as closely as possible to plant requirements and minimise losses from the soil are therefore valuable options. Exact practices however, need to be chosen for the specific crop and soil type, and while recent developments such as nitrification inhibitors show considerable promise, they have yet to be tested under a wide variety of field conditions and are currently much more expensive than standard fertilisers.

Rotational cropping is already practiced in many areas but optimising crop selection and particularly the addition of N fixing crops, can increase soil C storage and reduce mineral fertiliser requirements, and therefore overall GHG emissions and energy requirements. The climate mitigation potential of these options may be fairly low in comparison with some measures, but they are cheap options which should be easy to implement. Where possible, changing from rotational crops to permanent ones such as grassland or bio-energy crops may have greater benefits in terms of increased soil C storage and decreased GHG emissions due to reductions in soil disturbance. Planting grass in orchards and vineyards is a simple measure for improving C storage and reducing erosions while planting trees in field crops may be a particularly valuable measure in marginal agricultural areas where soil erosion can be a major

problem. They increase C storage and reduce leaching, and have a wide variety of other environmental benefits.

For pasture, careful management of grazing intensity can reduce CO_2 emissions and soil erosion and loss of SOC associated with overgrazing, while timing grazing periods to avoid wet periods, typically in spring and autumn, can reduce N_2O emissions from denitrification, which is strongly stimulated by trampling and manure and urine deposition on water logged ground. Keeping animals such as dairy cattle indoors and collecting waste for spreading on fields, rather than allowing them to graze outdoors and deposit waste directly, has a high potential for N_2O emission mitigation but drawbacks in terms of animal welfare, needing to feed animals with concentrates or silage and the associated costs, may make this option unfeasible. Improving grassland by sowing with more productive grass species or adding legumes, and increasing organic inputs, may improve C storage but this may be offset by increases in N_2O emissions, although these can be partially mitigated by careful management of grazing and reductions in soil disturbance.

The most promising measures to increase soil carbon contents are summarized in 5 categories as shown in the table below. Both reduced tillage intensity / frequency and avoiding fallow periods will take time to result in a clear increase in soil carbon content. Under the precondition that the productivity level is sustained, these two measures will have a considerable positive effect on the soil carbon content on a long term basis when they are implemented now. Both optimizing crop production and leaving behind crop residues will have an instant and clear positive effect on soil carbon content. Supply of organic matter from outside the farm will have an instant and clear positive effect on soil carbon content. However, this measure is not sustainable on a long run basis because availability of off farm organic matter is limited making it a scarce resource.

Measure	**Effects on soil carbon content at different time scales**		
	short	medium	long
Reduce tillage intensity / frequency	+	++	+++
Avoid fallow periods	+	++	+++
Optimize crop production	++	++	++
Leave behind crop residues	++	++	++
Supply organic matter	+++	++	+

1. Carbon management

This Deliverable 2.1 is framed into Work Package (WP) 2 titled "Current and future crop and soil management systems in Europe" and Task 2.1. The objective of Task 2.1 was to define key crops and soil management practices among the different European countries as they affect SOC flows and stocks and their applicability in various farming systems and agro-ecological zones in Europe.

1.1 Introduction

Most agricultural soils contain between 2 and 5% organic matter. Organic matter is a collective name for all kinds of compounds in which carbon is the basis, from small and soluble molecules to (woody) plants. Roughly 58% of organic matter in soils consists of carbon (C). Management of organic matter is important for both the farmer and the climate issue. This chapter describes what good carbon management is and why it is important. In addition, concrete measures are described that can be applied at the farm level.

1.2 Why is organic substance of interest?

Organic matter in the soil performs various functions. First of all, it ensures both retention and release of nutrients, especially nitrogen. In addition it creates and increases the water holding capacity of soils, allowing more water availability to plants. On sandy soils an increase in the organic matter content with 1% results in the release of 25 kg additional nitrogen per hectare and can retain the equivalent of 6 mm of rainfall in terms of extra moisture (Van Eekeren et al., 2007). Typically more organic matter also leads to improved workability and a lower resistance to penetration by e.g. crop roots. In addition, organic matter is food and provides energy for all kinds of soil organisms such as bacteria, protozoa nematodes and earthworms. These organisms in the soil food web are vital to the immobilization (storage and buffer) and mineralization (release) of nutrients. Others e.g. earthworms have a beneficial effect on the structure of the soil enhancing rooting, water infiltration into the soil and buffering and securing both organic matter and plant nutrients. A rich and diverse soil life may also provide better resistance to soil borne pests and diseases.

1.3 Organic matter: buildup and decomposition

Organic matter in the soil is made available to soils in the form of crop residues of main crops and green manures such as compost, manure or mushroom compost. In the soil, a fraction or all of the added organic matter is transformed (processed into new components) and decomposed (broken down to CO_2) by (micro-) organisms. On average, yearly 2% of the soil organic matter present (stock) is decomposed and returned to the atmosphere mostly as CO_2. Organic matter in soil can be divided into three categories: easy degradable, moderately stable and very stable organic matter. These different types of organic matter have different properties. So yields easy degradable material rapidly nutrients, while very stable organic matter especially contributes to improving the structure of the soil (Koopmans et al., 2007). The fraction of any added organic matter to soil that after one year is still present in the soil is called 'effective organic matter'. This is the organic matter believed to contribute most to formation of (stable) soil organic matter.

Organic matter that is broken down in the first year after application can be considered slow-release fertilizer (Koopmans et al., 2007).

1.4 Buildup of organic matter: depending on land use

Long term field trials in Belgium showed that more organic matter was built up under grassland than under arable land. After 36 years of permanent grassland, the top 10 cm of the soil contained 6% organic matter. On the same plot also 36 years of continuous cultivation of forage maize was practiced. In this case the soil contained 2% organic matter (Van Eekeren et al., 2011). The first years, buildup of organic matter under just sown grassland is the fastest. After a number of years (ranging from 10-100 years, depending on the soil type and moisture regime) a stable situation is reached, in which the organic matter content of the soil remains constant and increases no further when a balance is reached between supply and degradation (Van Eekeren et al., 2007). Both this stable level as well as the optimal amount of organic matter in soil varies by soil type. Not always: more is better – for example, when there is too much soil organic matter the bearing capacity goes down and machines may get stuck in relatively wet conditions and fields may be more difficult to work and manage. At high organic matter levels, the losses to air and water of C and nutrients may also relatively be higher than in soils with intermediate or optimal organic matter and nutrient contents.

1.5 Organic matter: carbon storage in the soil

Due to the increase in the concentration of greenhouse gases such as carbon dioxide (CO_2) in the atmosphere the global climate changes. These greenhouse gases act like a blanket causing the earth to loose less heat. Consequently sea level rises and floods and heavy rains, but also periods of drought, increase. Soils store large amounts of carbon, a sandy soil with 2.5% organic matter contains about 50 tons of carbon per hectare. If that store is maintained and secured and not decomposed (not broken down) then loss of C and emission of CO_2 is prohibited. In addition, soils can increase the stores of carbon by adding additional organic matter. Consequently, the soil can act as carbon sink for atmospheric CO_2 as this organic matter has to be produced by plants (photosynthesis from atmospheric CO_2 and subsequent transformation processes in animal, microorganisms or industry before or after returning the organic matter to soils. This process and sequence is clearly beneficial to the climate and prevent climate change: more carbon as organic matter in the soil means less carbon as CO_2 in the air. Carbon dioxide is not the only greenhouse gas: higher concentrations and emissions of N_2O and CH_4 also contribute to climate change. Farmers manage large areas of land and thereby influence the amount of carbon in the soil. Good carbon management thus serves critical societal issue. This chapter gives a brief outline on carbon in the soil and describes measures farmers can take to increase the organic matter contents in the soil.

1.6 Understanding carbon on farms

To achieve good carbon management, it is important to understand the carbon dynamics on farms. What measures can be taken to import carbon to add to soil and what measures help preventing decline in soil organic matter contents of soils? Periodic measurement of the organic matter content of a plot is certainly needed. The amount of organic matter that is stored in the soil is relatively large compared to annual increases or decreases in organic matter. In addition, the organic matter that was added recently has another quality than the organic matter present in the soil for years.

As a result, this increase or decrease is very difficult to measure – it will usually fall within the inaccuracy of the measurement method. A change in the organic matter content of the soil can only be determined over a period of years and more likely 10 or more than only 3-5 years. An organic matter balance can be a useful tool to understand the supply and removal of organic matter and the change in soil organic matter.

2. Measures to restrict breakdown and increase supply of organic matter

Table 1 gives an overview of practical measures for good carbon management, both for agriculture and for pastureland. These measures are further explained in chapter three through six. The measures are divided into three categories: first, measures which restrict the breakdown of organic matter. These measures are the most important because the quantity of organic matter in the soil is large and the rate of breakdown has a relatively large influence on the net carbon conservation. In addition, measures are described that ensure supply of organic matter of the own farm, and finally measures that ensure supply of organic matter from outside the farm. Organic matter inputs within the own farm is preferable to organic matter inputs from outside the farm. In the latter case it is unclear what negative side effects possible did occurred when capturing the organic matter (for example, emissions of other greenhouse gases).

The annex I – IV to this report provide further details on the measures that are detailed in chapter 3, the farming systems and decomposition rates across EU:

- Effects (changes in CO_2 equivalents for measures in terms of emissions from soil decomposition and removals from the atmosphere, effects on other issues and emissions (passing on effects) (Annex I)
- Description of the measures identified in the EU PICCMAT project (see http://www.climatechangeintelligence.baastel.be/piccmat/spaw/uploads/files/WP1_d3_Report.pdf) that are at the basis of this SmartSOIL list (Annex II)
- Listing of farming systems relevant for SmartSOIL (Annex III)
- Decomposition rates of organic matter in Europe for use in WP2 (Annex IV)

Table 1.
Measures to enhance the soil carbon content for arable and dairy farming. Grouping of measures into categories X, Y & Z with X: supply of organic matter from outside the farm, Y: additional production of organic matter on the farm by sequestration of CO_2 from the air, Z: reduction of organic matter loss by lowering the breakdown rate of organic matter in the soil.

Measures	Category	For arable or dairy farming?
Measures related to tillage :		
Non inversion tillage	Z	Arable Dairy
No tillage	Z	Arable Dairy
Grassland renewal optimization	Y, Z	Dairy
No plough	Z	
Re- and overseeding (periodic or continuous)	Y, Z	
Measures related to cropping pattern:		
Avoid summer fallow	Y, Z	Arable Dairy
Avoid winter fallow	Y, Z	Arable Dairy
Green manure crop/nitrogen catch crop/mowing manure	Y, Z	Arable Dairy
Crop rotation with annual crops	Y, (Z)	Arable
Crop rotation with perennials	Y, Z	Arable
Switch to woody crops	Y, Z	Arable
Placement of hedges	Y, Z	Arable Dairy
Measures related to optimizing crop production:		
Optimize irrigation	Y	Arable Dairy
Grazing management:		Dairy
Strip meadows and changing meadows	Y	
Additional seeding Grassland herbs and improved grass mixtures	Y	
More efficient fertilization	Y	Arable Dairy
Other measures:		
Soil additives: compost, animal manure, mowing manure	X	Arable Dairy
Leave crop residues	Y	Arable Dairy

3. Measures related to tillage

3.1 Non-inversion tillage

In case of non-inversion tillage, the soil is superficially torn and crumbled with discs and tooth, creating a loose and crumble topsoil. A large part of the crop residues will stay on the surface. This is also known as minimum tillage, reduced tillage or conservation tillage. Ploughing promotes the breakdown of organic matter by aeration of the soil, and results in physical degradation of crop residues and disruption of soil life (Franzluebbers and Follett, 2005). Non-inversion tillage reduces the breakdown of organic matter, and has a positive effect on soil life. In addition it improves the soil structure and leads to less compaction. However, reduced tillage implies also risks because crop residues remain on the land. This can lead to an increased risk of aboveground pathogens. In addition, non-inversion tillage is not possible for all crops. For tubers and beet non-inversion tillage is not suitable (Vasquez et al., 2008).

3.2 No tillage

In the case of no tillage special machines directly sown in the stubble, by cutting narrow slots for seeding. This is also called 'zero tillage' or 'no-till'. Advancements in techniques for weed control make it possible to grow crops without ploughing. Often also other parts of the production system need to be adjusted. Just like non-inversion tillage, no tillage reduces the breakdown of organic matter, and ensures improvement of soil life and soil structure (West and Post, 2020; Vasquez et al., 2008).

3.3 Grassland renewal optimization

3.3.1 No grassland ploughing

Under grassland organic matter accumulates: tests in Belgium showed that the organic matter content after 36 years of grassland was 6.1% in the upper 10 cm, while under permanent arable cultivation it was 2.1%. The organic matter content of a crop rotation of 3 years corn and 3 years grass was in between (3.4%) (Van Eekeren et al. 2007). When grassland is plowed a lot of air enters the soil. As a result, the organic matter quickly breaks down. In addition, disrupting the sod is unfavorable for soil life. Especially populations of earthworms may show a strong decline, while commonly it takes at least five years before they have fully recovered. In permanent pasture earthworms can provide good structure and contribute to water infiltration. When the grassland produces enough, it is therefore recommended to leave the grassland intact and not to plow. Ploughing of grassland is restricted by legislation: on sands and loams grassland may only be plowed between February 1 and May 10. On clay and peat soil this may to 15 September. On all soil types immediately after ploughing a nitrogen deficient crop needs to be sown. The rules on ploughing of grassland have been drawn up with a view to limit leaching of nitrogen, but they are also beneficial for reducing N_2O emissions: spring ploughing leads to lower emissions than autumn ploughing (Kasper et al. 2002).

3.3.2 Grassland renewal optimizing: overseeding

When grassland production has become too low, and/or the botanical composition of the grass is too much deteriorated, grassland renewal is needed. Composition of the grassland can be

assessed on the basis of the following criteria: when < 50% is English rye grass, or > 10% weeds localized or 20% weeds distributed, grassland renewal is desirable (Hamilton, 2006).
Also when there are problems with dewatering or when a plot is not leveled grassland renewal can be considered. Grassland renewal may be delayed by good maintenance. More details are given in section 3.3.3. Grassland renewal does not necessarily implies ploughing: overseeding is also a possibility. Because less air inters the soil, less organic matter is broken down. Also, the old sod provides carrying capacity with less chance of structure problems when travelled. Overseeding is faster and less labor intensive than re-seeding: instead of five work passes (chemical sod killing, harrowing, ploughing, sowing bed preparation and sowing) only one pass is required (sowing in the existing sod, possibly after chemical sod killing). In addition, overseeding can be done in autumn, when there is generally less work pressure than in the spring. Also overseeding is cheaper than re-seeding. A risk of overseeding is that the new grass mixture does not get well established due to competition with the old sod.

4. Measures related to cropping patters

4.1 Avoid summer and winter fallow

Under fallow soil organic matter breaks down faster than when a crop is grown. Keeping the land covered ensures that soil organic matter breaks down more slowly than in the case of black fallow. In addition, black fallow misses the opportunity to capture carbon from the air in crops. It is therefore advisable to avoid fallow, both in summer and winter.

4.2 Green manure crop/nitrogen catch crop/mowing manure

Green manure or catch crop is usually sown to avoid leaching and loss of nutrients in autumn. Also from the point of view of organic matter management it is favorable to grow green manure or a catch crop and to avoid winter fallow. Such a crop will sequester carbon on farm – a difference with the import of carbon sequestered elsewhere such as compost. Because the crop is ploughed into the soil, the captured organic matter is added to the soil. Part of it will break down quickly soon, but yet also effective organic matter is added to the soil, which breaks down much more slowly. Timing is crucial for the success of a green manure crop: the earlier the crop is sown in late summer or early fall, the better. A green manure crop sown after 1 October has usually little chance of success.

4.3 Crop rotation with annual crops

With a multiple year intensive cultivation, such as corn, the soil organic matter content decreases. This is due to intensive soil tillage, and because there is little supply of organic matter from crop residues. Annually alternating crops avoid this. Alternation with grain in the cropping pattern allows for accumulation of organic matter via crop residues (straw), but also the relatively large root system supplies a decent amount of organic matter after harvesting. Alternation with grass (clover) or a green manure crop that is not harvested but is completely plowed into the soil not only ensures the retention of nutrients in the soil, but also contributes a lot of organic matter.

4.4 Crop rotation with grass and corn

When pasture is renewed a crop rotation with corn is possible. The corn can take advantage of the released nutrients in the ploughed grassland, and grass clover grows well on a poor corn stubble. For soils under continuous corn cultivation it is beneficial to alternate the corn with some years of grassland. However, it is not recommended to plough permanent grassland to grow corn for only one or a few years. The losses of organic matter after ploughing are very large, and it takes a long time for this organic matter is built up again. In addition, the risk of losses of nitrogen through leaching after ploughing of permanent grassland is large (Klein Swormink et al., 2010).

4.5 Crop rotation with perennials or woody plants

Sequestration of carbon is mainly taken part in the plant itself by absorption of carbon dioxide from the air. In addition, perennials and woody plants that are grown in open fields, firmly capture the soil with their roots.

On slopes this prevents erosion and loss of organic matter, and in areas prone to wind erosion disappearance of organic matter is limited. Deciduous plants and crops through their leaf litter annually contribute to increase in soil organic matter.

When the pruning waste of perennials or woody plants remains on the land extra supply of organic matter in the soil is realized. During harvest of perennials or woody plants remaining roots, falling leaf and possibly pruning waste also contribute.

4.6 Placement of hedges

As with perennials and woody plants carbon sequestration takes place in the plant itself. In the case of hedges sequestration is much longer-lasting because they remain permanently and the soil is not tilled. Also hedges contribute to holding soil particles in place which reduces the risk of erosion by water and wind. Leaf litter and pruning waste contribute to organic matter accumulation in the soil. Shredding of pruning waste allows for faster conversion to organic matter contributing to soil quality.

5. Measures related to optimizing crop production

5.1 Optimize irrigation

When insufficient soil moisture is available crop growth is hampered. This is unfavorable for production and for carbon sequestration by the crop. Planning irrigation in accordance with the circumstances avoids occurrence of moisture deficits.

5.2 Grassland production optimization: grazing and mowing management

Grassland often contains significantly more carbon than arable land. This is due to the relatively lower decomposition rate under grassland, because no soil tillage takes place, and because of the higher supply of organic matter. The supply of organic matter under grassland is positively influenced by rooting of grassland and grazing losses. However, grazing losses are undesirable for the farmer. To keep the organic matter content of grassland as high as possible and to optimize production, it is especially important to optimize the rooting. The latter is only possible when taking into account the way grasses grow. Grasses have adapted evolutionary to grazing building up reserves in the roots. After grazing the grass extracts sugar and amino acids from the roots and stubble for above-ground growth. As a result, a part of the roots die and they become available for soil life and turn into soil organic matter. Above ground regrowth starts from the growing points that are close to the soil (Ourry et al., 1989; Sullivan and Spraque, 1949). In grassland management it is important to make sure that the grass has sufficient possibilities to replenish the root reserves. A dairy farmer can influence this by choosing a specific grazing method and frequency of mowing or grazing. At a too high frequency of grazing or mowing rooting decreases (Schuurmans, 1954; Eddy, 1981). The intensity of grazing or mowing is thus important for the supply of organic matter.

5.2.1 Strip grazing

Strip grazing is a form of grazing whereby the cattle has access to a strip of grass that is sufficient for a day. Over or undergrazing can be prevented with strip grazing, because the cattle is moved every day which makes adjusting easy. In addition the grass has enough time to recover from the root reserves. Strip grazing is therefore the most appropriate method for the optimization of carbon contents of grassland and to use the grass for milk production.

5.2.2 Permanent temporal pastures

At permanent pastures cows have access to a large area of grass, where they graze for a longer time period (> 14 days to several months). At temporal pastures cattle are rotated to different pastures every two to six days. As a consequence, multiple (smaller) pastures are required adapted to the stocking density. Permanent pastures can lead to a higher root mass than temporal pastures, when the optimal stocking density is not exceeded (Davis, 1985). The grass is kept at a length of 7-8 cm allowing photosynthesis to remain relatively constant. In this case less claims are made on grass root reserves for sprouting compared to temporal pastures. However, when the grass is too short at permanent pastures due to high stocking densities, then rooting decreases.

5.2.3 Mowing

In general, frequent mowing has a negative effect on the above ground yield and rooting. English rye grass has an optimum for rooting at 8 weeks mowing (Dawson, 2000). Short and frequent mowing generally has a lower temporary root growth (Evans, 1971). Therefore it is recommended to decrease the mowing frequency and to strive for heavier cuts. In this way, rooting can optimal restore (Van Eekeren et al., 2011a). Under wet conditions grazing as well as riding on grassland is not recommended. Structure problems can easily arise thereby hampering good rooting.

5.3 Optimization of grassland production: grassland maintenance

Good grassland maintenance allows the production to remain high. Grassland maintenance consists of a combination of grassland treatment and additional seeding. Removal of weeds and less good grasses in springtime is recommended. Next additional seeding is possible with about 20 kg of grass seed per hectare, depending on the state of the sod. Additional seeding has a positive effect on the yield and on the nutritional value of the grass, by the higher proportion of good grasses in the sod. German research showed that the yield of permanent grassland with annually additional seeding, is 15% higher than of grassland in which this was not applied. In addition, the average nutritional value increased by 5%
(Hamidi, 2012).

5.4 Grassland production optimizing: grassland herbs and improved grass varieties and mixes

Eventually grass roots are turned into organic matter. Therefore good rooting is important for building up soil organic carbon. Deep and intensive rooting has more benefits. Enhanced rooting ensures higher nutrient utilization. In addition, rooting depth determines from which soil layer water can be taken up. Grass with a deep root system it more resistant to drought. In addition, roots contribute to soil structure, serve as nutrition for soil life and contribute to the control of weeds (Van Eekeren et al., 2011a).

5.4.1 Measure: sow grassland herbs.

Generally grasses have a fine root system. Species such as Plantago lanceolata and Buttercup have a coarse root system, while for example alfalfa, red clover, chicory and dandelion form a taproot (Van Eekeren et al., 2011). Practice has shown that red clover for example, blends well with Reed (De Wit et al., 2012). It is beneficial to combine species with different types of root systems: as a result, the soil is optimal rooted. Next this is beneficial for the nutrient utilization and building up of soil organic matter.

6. Other measures

6.1 Adding animal manure and compost

With compost and animal manure organic matter is added to the soil. Part of this organic matter is broken down rapidly. The organic matter that remains after one year is called effective organic matter. Not every type of manure is the same: slurry is, for example, much more degradable than straw yard manure.

6.2 Adding mowing fertilizer

As described the cultivation of green manures and catch crops capture extra carbon on the farm. Instead of ploughing under green manures such as grass-clover and alfalfa, they can also mowed and added as mowing fertilizer to another plot. That offers a farmer an additional ability manage nitrogen and carbon flows on his farm.

6.3 Leave behind crop residues

Crop residues are often removed from the land to be used as straw in stables, as animal feed or as a source of energy. However they can also remain on the land, and supply additional carbon to the soil. The contribution of crop residues to soil organic matter differs per crop. Crop residues with lots of carbon and little nitrogen are usually less easily broken down than crop residues with relatively less carbon.

7. Measures to restrict breakdown and to increase supply of organic matter

7.1 Three categories

Table 1 gives an overview of practical measures for good carbon management, both for agriculture and for pastureland.

The measures are divided into three categories:

1 Measures which restrict the breakdown of organic matter. These measures are the most important because the quantity of organic matter in the soil is large and the rate of breakdown has a relatively large influence on the net carbon conservation. Category Z in Table 1.

2 Measures which ensure supply of organic matter on the own farm.
Category Y in Table 1.

3 Measures which ensure supply of organic matter from outside the farm.
Category X in Table 1.

Organic matter inputs within the own farm is preferable to organic matter inputs from outside the farm. In the latter case it is unclear what negative side effects possible did occurred when capturing the organic matter (for example, emissions of other greenhouse gases).

7.2 Concrete measures

Based on Table 1, the following five measures are considered to be the most promising ones to enhance soil carbon contents:

1 Reduce tillage intensity and/or frequency going from intensive tillage including frequent ploughing towards non-inversion tillage and eventually no-tillage. This reduced tillage will enhance soil carbon conservation (category Z). However, for tubers and beet reduced tillage is not a realistic option.

2 In terms of cropping pattern it is attractive to avoid fallow periods by for instance sowing green manure crops to avoid winter fallows. Moving from a cropping pattern allowing fallow periods towards a pattern that does not allow fallow periods increases soil carbon supply on farm (category Y).

3 In terms of crop production optimization supply of sufficient water and nutrients at the right time and place increases biomass production. In addition, also choice of the right grassland mixtures and their grazing and mowing management increase biomass production and thus increase carbon supply on farm (category Y).

4 Other measures such as leaving behind crop residues (category Y)

5 Other measures such as applying soil additives (compost, animal manure, mowing manure: category X) increase the supply of organic matter.

In summary, it is recommended to keep the organic matter that is already there by reducing its breakdown caused by intensive and frequent tillage. Increase organic matter supply on farm by optimizing cropping patterns (no fallow period) and by optimizing crop production (sufficient supply of water and nutrients) are Also effective measures. Leaving crop residues on the field and applying compost and manure also increases soil carbon content The five measures and their main characteristics are summarized in Table 2. Both reduced tillage intensity / frequency and avoiding fallow periods will take time to result in a clear increase in soil carbon content. Under the precondition that the productivity level is sustained, these two measures will have a considerable positive effect on the soil carbon content on a long term basis when they are implemented now. Both optimizing crop production and leaving behind crop residues will have an instant and clear positive effect on soil carbon content. Supply of organic matter from outside the farm will have an instant and clear positive effect on soil carbon content. However, this measure is not sustainable on a long run basis because availability of off farm organic matter is limited making it a scarce resource.

Table 2.
Promising measures to enhance soil carbon contents and their main characteristics at a short, medium and long term time scale.

Measure	**Effects on soil carbon content at different time scales**		
	short	medium	long
Reduce tillage intensity / frequency	+	++	+++
Avoid fallow periods	+	++	+++
Optimize crop production	++	++	++
Leave behind crop residues	++	++	++
Supply outside organic matter	+++	++	+

References

Arrouays D., Balesdent J., Germon J.C., Jayet P.A., Soussana J.F., Stengel P., 2002. Increasing carbon stocks in French agricultural soils? B. Seguin et al. (Eds) Moderating the impact of agriculture on climate. INRA, Paris.

Boogaard, H., J. Wolf, I. Supit, S. Niemeyer, M. van Ittersum. 2013. A regional implementation of WOFOST for calculating yield gaps of autumn-sown wheat across the European Union. Field Crops Research, Vol.143, pp.130-142.

Deinum B. 1985. Root mass of grass swards in different grazing systems. Netherlands Journal of Agricultural Science 33, 377-384.

Deru, J., G.J. van der Burgt, N. van Eekeren, H. Wientjes. Maïsteelt en mestscheiding, langetermijneffecten op organische stof, V-focus december 2010, pp. 21-22.

Deru, J.G.C., N.J.M. van Eekeren, H. de Boer. 2010. Beworteling van grasland - een literatuurstudie: Nutriëntenopname in relatie tot bewortelingsdiepte en -intensiteit; factoren en potentiële maatregelen die de beworteling beïnvloeden. Rapport 2010-018LBV. Louis Bolk Instituut, Driebergen. 63 p.

Deru, J.G.C., N.J.M. van Eekeren, J. Visscher, H. Schilder. 2011b. Grote variëteit in Engelse raaigrassen. V-focus. Februari 2011, p. 22-23.

Deru, J.G.C., N.J.M. van Eekeren, J. de Wit, H. de Boer. 2011a. Effect van grassoort en N-bemestingsniveau op productie, beworteling en N-mineraal in de herfst: Veldproef op zandgrond met Engels Raaigras, Kropaar en Rietzwenkgras. Rapport 2011-017 LbD. Louis Bolk Instituut, Driebergen. 22 p

De Willigen, P., B.H. Jansen, H.I.M. Heesmans, J.G. Conijn, G.J. Velthof, W.J. Chardon. 2008. Decomposition and accumulation of organic matter in soil; comparison of some models. Wageningen, Alterra-rapport 1726, ISSN 1566-7197.

De Wit, J., J.G.C. Deru, N.J.M. van Eekeren. 2012. Mengsels met kropaar of rietzwenkgras interessant voor maaipercelen. V-focus, juni 2012, pp. 29-31.

Ennik G.C., 1981. Grasgroei en beworteling. CABO-verslag nr. 38, Centrum voor Agro Biologisch Onderzoek, Wageningen.

Franzluebbers, A.J., R.F. Follett. 2005. Greenhouse gas contributions and mitigation potential in agricultural regions of North America. Soil Tillage Research 83: 25-52

Hogenkamp, W. 2012. Twee ton extra droge stof. Bijzaaien moet vast tussen de oren zitten. Boerderij 97 (26).

Hoving, I.E. 2006. De HerinzaaiWijzer als hulpmiddel bij afweging van graslandvernieuwing, PraktijkRapport Rundvee 82, Animal Sciences Group, 16 p.

Kasper, G.J., A. van den Pol-van Dasselaar, P.J. Kuikman, J. Doling, 2002. Beperking van lachgasemissie na scheuren en bij vernieuwing van grasland; eindrapport reductieplan overige broeikasgassen landbouw cluster 1 Alterra-rapport 560.5, Wageningen. 37 p.

Klein Swormink, B., N. van Eekeren, B. Philipsen, Graslandsignalen. Praktijkgids voor optimaal graslandgebruik. Roodbont B.V., Louis Bolk Instituut, 2008, 96 p.

Koopmans, C., J. Bokhorst, C. ter Berg, N. van Eekeren. Bodemsignalen, Praktijkgids voor een duurzame bodem. Roodbont B.V., Louis Bolk Instituut, 2007.

Lal, R. and Bruce, J.P. 1999. The potential of world cropland soils to sequester C and mitigate the greenhouse effect. Environmental Science and Policy 2: 177-185

Li C, Frolking S, Butterbach-Bahl K (2005) Carbon sequestration in arable soils is likely to increase nitrous oxide emissions, offsetting reductions in climate radiative forcing. Climatic Change 72: 321-338.

LNV-loket, 2012. Scheuren van grasland, op: http://www.hetlnvloket.nl/onderwerpen/mest/dossiers/dossier/scheuren-van-grasland-en-vanggewassen/scheuren-van-grasland.

Meyer-Aurich A, Weersink A, Janovicek K, Deen B (2006) Cost efficient rotation and tillage options to sequester carbon and mitigate GHG emissions from agriculture in Eastern Canada. Agriculture Ecosystems & Environment 117: 119-127

Ogle S, Breidt, F, Paustian, K (2005) Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. Biogeochemistry 72: 87-121.

Ourry A., Bigot J., Boucaud J., 1989. Protein mobilization from stubble and roots, and proteolytic activities during post-clipping re-growth of perennial ryegrass. Journal of Plant Physiology 134: 298-303.

Rietberg, P.I., Ter Berg, C., 2012. BioKennisbericht Groene maaimeststoffen. Louis Bolk Instituut, DLV Plant, 5 p.

Rietberg, P.I., B. Luske, A. Visser, P.J. Kuikman (2013) Manual good carbon management (in Dutch). Louis Bolk Institute, Driebergen, the Netherlands. Report 2013-002 LbP, pp. 29 (http://www.louisbolk.org/nl/publicaties?ht_search=1&ht_also_above5years=1#books_and_reports).

Schuurmans J.J., 1954. De bewortelingsproblemen op grasland. In: De plantenwortel in de landbouw. Voordrachten in het kader van het Nederlands Genootschap voor Landbouwwetenschap.

Smith P, Powlson DS, Glendinning MJ, Smith JU (1997) Potential for carbon sequestration in European soils: preliminary estimates for five scenarios using results from long-term experiments. Global Change Biology 3: 67-79

Smith P, Goulding KWT, Smith KA, Powlson DS, Smith JU, Falloon P, Coleman K (2000) Including trace gas fluxes in estimates of the carbon mitigation potential of UK agricultural land. Soil Use and Management 16: 251-259.

Sullivan J.T., Sprague V.G., 1949. The effect of temperature on the growth and composition of the stubble and roots of perennial ryegrass. Plant Physiology 24: 706-719.

Van Eekeren, N., B. Philipsen, M. Hanegraaf. 2007. Blijvend grasland of gras klaver in rotatie met snijmaïs, V-focus, oktober 2007, pp. 24-25.

Van Eekeren, N.J.M., J.G.C. Deru, H. De Boer, B. Philipsen. 2011a. Terug naar de graswortel. Een betere nutriëntenbenutting door enen intensievere en diepere beworteling. Rapport 2011-023 LbD. Louis Bolk Instituut, Driebergen.

Van Eekeren, N., G.J. van der Burgt, B. Philipsen, H. van Schooten, M. de Haan. 2011b. Effect op organische stof en kosten/baten, vruchtwisseling van gras en maïs, V-focus april 2011, pp. 24-26.

West, T.O., W.M. Post. 2002. Soil organic carbon sequestration rates by tillage and crop rotation: a global data analysis. Soil Science Society America Journal 73: 312-316

Annex I Effects and ‘passing on effects’ for each promising measure

Categorisation:
X: supply of organic matter from outside the farm
Y: additional production of organic matter on the farm by sequestration of CO_2 from the air
Z: reduction of organic matter loss by lowering the breakdown rate of organic matter in the soil
SOC = soil organic carbon, a = arable farming, d = dairy farming.

Where numbers are given on climate effects these are in tonnes CO_2 equivalents per year, a negative value indicates emission of greenhouse gases or breakdown of soil carbon. Business economic and other effects are categorised into classes: ++ always and everywhere positive (for the environment, i.e. (for example) reduction of emission) + mostly positive, 0 no effect, - mostly negative, -- always and everywhere negative,? unknown, * effect depending on exact application of the measure. This classification indicates the direction of the effect, but not the size of the effect. For example ++ for NH_3-emission means that the effect of this measure is certainly positive (so the NH_3 emission decreases), but its contribution to the reduction of the total NH_3 emissions can, however, be very small. The information is based on Rietberg et al., (2013).

	Category	**Applicable for sector**	**SOC**	**Soil emissions (N_20 and CH_4)**	**Avoided chain / indirect emissions**	**Total SOC and emissions**	**Business economics**	**NH_3 emission**	**Fine dust**	**Odour**	**Leaching NO_3**	**Soil quality**	**Water quality**	**Above ground biodiversity**	**Soil biodiversity**	**Animal welfare**	**Use of crop protection agents**
			Direct effects on the soil				Other effects										
Measured related to tillage:																	
Non inversion tillage	Z	a, d	1,09	0,08	0,08	1,25	0		0	0	+	++	+	0	+	0	-
No tillage	Z	a, d	1,04	0,08	0,14	1,04	0		+	0	+	++	++	0	++	0	--
Grassland renewal optimization	Y, Z	d					+	0	0	0	+	+	0	0	0	0	0

No plough	Z	d															
Overseeding (periodic or continuous)	Y, Z	d															
Measures related to cropping patterns:																	
Avoid summer fallow	Y, Z	a, d	0,48	-0,03	-0,13	0,32	0	-	+	0	+	+	+	0		0	-
Avoid winter fallow	Y, Z	a, d	0,83	0,25	0,61	1,69	0	-	+	0	++	+	+	0		0	-
Green manure / nitrogen catch crop	Y, Z	a, d					+	0	0	0	++	++	++	0	+	0	-
Crop rotation with annual crops		a	0,58	0,07	0	0,65	0		0	0	+	+	+	0		0	0
Crop rotation with perennials		a	0,57	0,03	0,17	0,77	-		0	0	+	+	+	0		0	0
Switch to woody crops		a	2,71	0,76	1,78	5,24	-		0	0				0		0	0
Placement of hedges	Y, Z	a, d	2,72	0,76	1,51	4,97	-	0	0	0		+		+		+	0
Measures related to optimizing crop production:																	
Optimize irrigation	Y	a, d	1,46	-0,42	-1,38	-0,34	+		0	0	+		+		0	0	
Grazing management		d	1,04	-0,79	-1,08	-0,83											
Rotation grazing	Y	d	2,20	0,05	0	2,25	+			0	+	+	+			+	0
Improved grass mixtures	Y	a, d	2,44	-0,94	0	1,50	+			0				++	++	+	0
Other measures:																	
Soil additives	X	a, d					-					+					
Compost	X	a, d	Depending on the type of compost en way of making compost					*		+	*	+	*		+	0	
Animal manure	X	a, d	Depending on the type of manure					-		+	*	+	*		+	0	
Leave crop residues, mowing manure	X, Y	a, d	Depending on the type of crop					*		-	*	+	*		+	0	

Annex II Description of PICCMAT measures

Within the PICCMAT project 26 measures for mitigation of greenhouse gasses from agriculture were selected. These measures formed the basis for eight case studies in six countries. However, within the case studies only a selection of the identified measures was relevant and was described in more detail. For the calculation of the mitigation potential with Miterra only the measures that were used in at least two case studies have been selected. This resulted in 10 measures, which are catch crops, zero tillage, reduced tillage, residue management (no removal and composting), optimising fertilizer application, fertilizer type, rotation species, adding legumes, agro forestry and grass in orchards and vineyards. These measures are briefly described below, based on PICCMAT deliverable D3: Practices description and analysis report.

Catch crops (CC)
The provision of temporary vegetative cover between agricultural crops, which is then ploughed into the soil is termed catch crop, but also other terms as green manure and winter crops are used. These catch crops add carbon to soils and may also extract plant-available N unused by the preceding crop, thereby reducing N_2O emissions and reducing amount of fertilizer N that needs to be added.

Zero tillage (ZT)
Advances in weed control methods and farm machinery now allow many crops to be grown without tillage (zero tillage or no till). In general, tillage promotes decomposition, reducing soil C stores and increasing emissions of GHGs, through increased aeration, crop residue incorporation into soil, physical breakdown of residues, and disruption of aggregates protecting SOM. Therefore zero tillage often results in soil C gain.

Reduced tillage (RT)
Reduced tillage or conservation tillage can take many forms including ridge tillage, shallow ploughing and rotovation or scarification of the soil surface. All cause less soil disturbance than conventional deep tillage with a mouldboard plough. Reduced tillage decreases decomposition, increases soil carbon stocks and decrease GHG emissions by decreased aeration and crop residue incorporation. Adopting no-till may also affect emissions of N_2O, but the net effects are inconsistent and not well-quantified globally.

Residue management (RM1, RM2)
Residue incorporation, where stubble, straw or other crop debris is left on the field, and then incorporated when the field is tilled, is used in some areas for water conservation, but also enhances carbon returns to the soil, thereby encouraging carbon sequestration. However, incorporation can increase N_2O emissions and therefore net benefits in terms of climate mitigation may be highest when residues with high N content are removed. Composting these residues and then returning them to the soil may reduce N_2O emissions in relation to incorporation untreated, while retaining benefits in terms of reduced requirements for mineral fertiliser. Therefore two main types of residue management can be distinguished, which have different effects on carbon and nitrogen:

1. Leaving crop residues on the field instead of burning or removal
2. Composting of crop residues and returning them to the field

Optimising fertilizer application (FA)
This measure can be subdivided into 3 options: changing fertiliser rates, fertiliser placement / precision farming and fertiliser timing / split application. Being more efficient in your fertilizer application (at the right time of the crop growth and under the most optimal weather and soil conditions) gives a change to lower the fertilizer rates. Precision farming and placement is giving the right amount of fertilizer at the right time and can reduce fertilizer use. A correct timing of fertilizer application, e.g. not under wet conditions which lead to a higher emission, and split applications of N will lower the emission of N_2O.

Fertilizer type (FT)
Three types of fertilizer exist (standard fertilizers, fertilizers with nitrification inhibitors and slow release fertilizers). Each type and each subtype have their own influence on the emission of ammonia (related to crop type (arable/grass), temperature, soil type etc.). Optimizing the choice of fertilizer might therefore decrease emission of N_2O. Nitrification inhibitors are compounds which prevent the turnover of ammonia into nitrate. They can be applied in animal manure and fertilizer and can lead to a decrease in fertilizer use or a higher N uptake in arable crops and grassland. Slow release fertilizers are fertilizers in which N is slowly released. So there might be less losses of fertilizer and fertilizer application can be reduced. They also reduce the emission factor of N_2O from fertilizer.

Rotation species (RS)
This measure consists of inclusion of different crop types in crop rotations (growing various crops on the same piece of land in a planned sequence), which can considerably increase carbon sequestration. This includes (i) use of more forage crops in rotations; (ii) replacement of continuous two-course rotations of row crops with crop rotations of winter cereals; (iii) elimination of summer fallow; (iv) use of more winter crops; (v) winter cover crops.

Adding legumes (AL)
Adding nitrogen-fixing crops such as beans, peas, soya or clover to rotations of cereals reduces N fertiliser requirements and related emissions, and can increases soil organic carbon. Legumes can be included into cereal rotations as a separate crop, as a second crop (when the land would otherwise be bare fallow) or under the major crop.

Agroforestry (AF)
Growing farmland trees (tree crops, shelterbelts, hedgerow, alley cropping) is a practice of allowing trees and crops to grow together. Windbreaks and shelterbelts are single or multiple rows of trees or shrubs planted for environmental purposes. Alley cropping can be implemented in marginal agriculture. Research has documented optimal tree planting levels to be from 3 to 6 % of the cropped field area. The species, location, layout, and density of the planting depend on the purpose and planned function of the practice. The best trees to grow together with crops are those with deep roots so they do not compete with crops for water and nutrients.

Grass in orchards and vineyards (GG)
Growing grass will protect soil the soil against erosion and improve soil properties on orchards and vineyards. Grass usually is ploughed under or desiccated to accommodate the primary crop being produced on the site. This practice is used to control erosion, add fertility and organic material to the soil, improve soil texture, and increase infiltration and aeration of the soil.

Measure	Assumptions
Catch crops	– Ogle et al. (2005) reported increases in soil organic carbon of around 7-11% over 20 years, based on a meta-analysis of studies from a range of countries and climatic and agricultural systems. – Arrouays et al. (2002) found that catch crops in France increase SOC by around 0.15 ton C ha^{-1} yr^{-1}.
Zero tillage	– West and Post (2002) calculated an increase in SOC of 7% based on a global data set. – Ogle et al. (2005) found increases of SOC of 10-13% for dry temperate regions and 16-18% for moist temperate regions. – Smith et al. (1997) showed that zero tillage can enhance soil C by 0.73% of the existing stock per year based on a number of long term zero tillage studies in Europe.
Reduced tillage	– Arrouays et al. (2002) reported increases in soil C stocks due to reduced tillage of 0.21 ton C ha^{-1} yr-1 in France. – Ogle et al. (2005) found an increase in SOC of 3-6% based on a meta-analysis of a global data set.
Residue management – no removal	– A modelling study using DNDC calculated that increasing residue incorporation from 15 to 90% for a maize-wheat system in China would sequester 680 kg C ha^{-1} yr^{-1} (Li et al., 2005). – Smith et al. (2000) argue that the incorporation of cereal straw across Europe would have a net positive effect with increased N_2O emissions being outweighed by the increases in SOC storage.
Residue management – composting	No quantitative data, but effects for C will be similar to the residue management - no removal
Optimising fertilizer application	No effect on C
Fertilizer type	No effect on C
Rotation species	– Meyer-Aurich et al. (2006) found an increase in SOC of -0.073 to 0.513 ton C ha^{-1} $year^{-1}$ depending on the type of rotation. – For a 20 year period crop rotation gave an increase of soil carbon of 3.8 ton C or 0.19 ton C ha^{-1} $year^{-1}$.
Adding legumes	No quantitative data
Agro forestry	No quantitative data
Grass in orchards and vineyards	– Growing grass in orchards and vineyards can increase the amount of carbon in the soil at a sequestration rate of 1 to 2 ton C ha^{-1} $year^{-1}$ (Lal et al., 1999).

Annex III Farming system

The farming systems have been derived from the SEAMLESS project[1]. In that project a classification was developed which distinguished 21 farm types, which could be further characterised by intensity (3 classes) and size (3 classes). A detailed description can be found in Andersen (2010). For SmartSoil we aggregated these 21 farm types into the following six main farming systems: Field crops, Permanent crops, Pasture and grasslands, Industrial crops, Horticulture and Mixed farms (Table 1). The farm types and farming systems can be expressed in number of farms or number of hectares. Data for Romania, Bulgaria, Cyprus and Malta is missing.

Table 1. Seamless farm types and grouping to main farming system

Code	SEAMLESS farm type	Main farming system
1	Arable/Cereal	Field crops
2	Arable/Fallow	Field crops
3	Arable/Specialised crops	Industrial crops
4	Arable/Others	Field crops
5	Dairy cattle/Permanent grass	Pasture and grasslands
6	Dairy cattle/Temporary grass	Pasture and grasslands
7	Dairy cattle/Land independent	Mixed farms
8	Dairy cattle/Others	Mixed farms
9	Beef and mixed cattle/Permanent grass	Pasture and grasslands
10	Beef and mixed cattle/Temporary grass	Pasture and grasslands
11	Beef and mixed cattle/Land independent	Mixed farms
12	Beef and mixed cattle/Others	Mixed farms
13	Sheep and goats/Land independent	Mixed farms
14	Sheep and goats/Others	Mixed farms
15	Pigs/Land independent	Mixed farms
16	Pigs/Others	Mixed farms
17	Poultry and mixed pigs/poultry	Mixed farms
18	Mixed farms	Mixed farms
19	Mixed livestock	Mixed farms
20	Horticulture	Horticulture
21	Permanent crops	Permanent crops

[1] http://www.seamless-ip.org

Annex IV Decomposition rate of organic matter in Europe

Currently a decomposition rate k_{ref} of 1.3 % organic matter per year across the whole of Europe is used in the SmartSoil project. However, it is know that this rate highly depends on the prevailing temperature and moisture regime across Europe (De Willigen *et al.*, 2008). As a consequence, it is desirable to differentiate the average European decomposition rate for different European regions.

The combined effect of temperature and moisture content on the actual decomposition rate k_{act} can be described by:

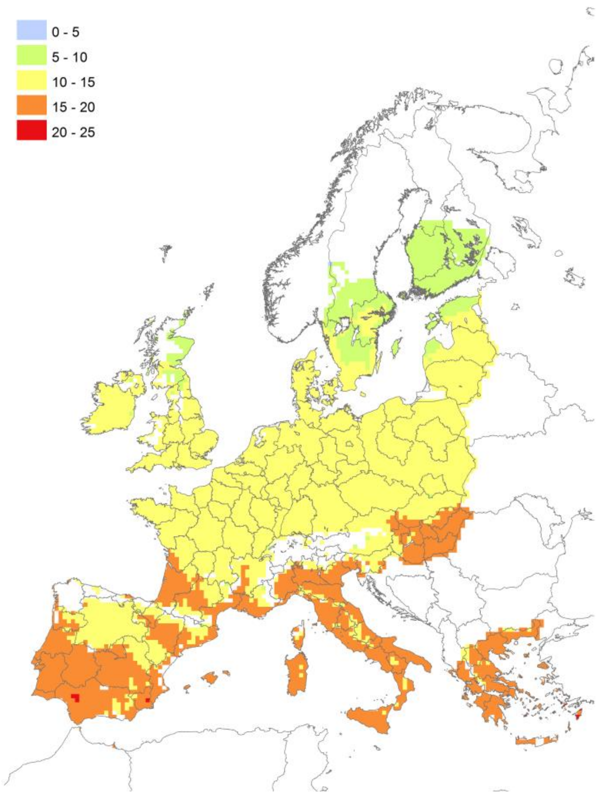
$$k_{act} = k_{ref} \cdot e_T \cdot e_m$$

Where the temperature response e_T increases or decreases by a factor two with a temperature change of 10 degrees with respect to the reference temperature (10 °C):

$$e_T = 2^{[(T - T_{ref}) / 10]}$$

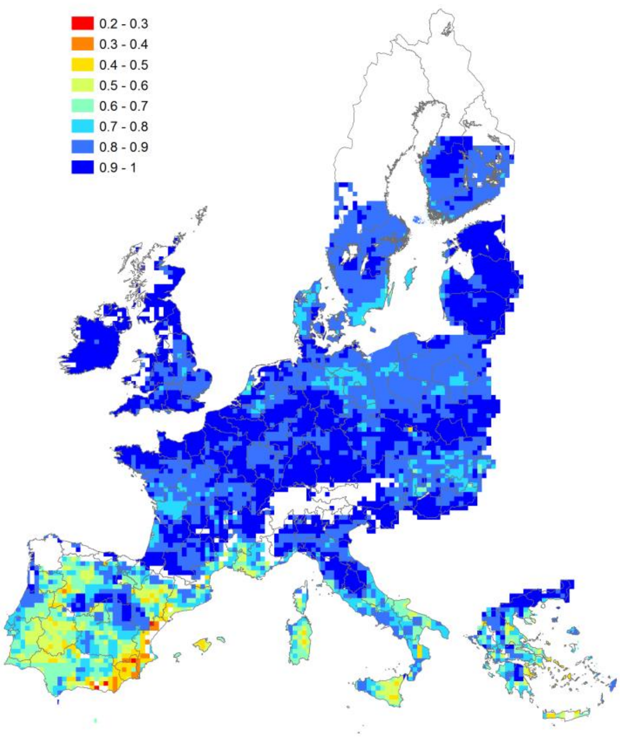
The response to moisture content is assumed to be indicated by the relative crop transpiration (RTRA, i.e. actual / potential evapotranspiration). In case of sufficient moisture RTRA will be 1 and also e_m is set at 1. In case of moisture deficit, RTRA will be < 1 and e_m is assumed to be equal to RTRA.

Figure 1 shows the long term daily mean temperature °C in April – June according to Boogaard *et al*. (2012).



Lowest mean temperatures for Northern Europe are 5 °C, for Central Europe they are 10 °C (equal to the reference temperature), and for Southern Europe they are 15 °C.

Figure 2 shows the relative crop transpiration for simulated water-limited growth and production of autumn-sown wheat according to Boogaard *et al*. (2012).



Relative crop transpiration for Northern and Central Europe is approximately 1, while this value for Southern Europe is 0.7.

Table 1 shows the resulting values for e_T, e_m, k_{ref} and k_{act}.

	e_T	e_m	k_{ref}	k_{act}
North: T = 5 °C	0.7	1	1.3	0.9
Central: T = 10 °C	1	1	1.3	1.3
South: T = 15 °C	1.4	0.7	1.3	1.3

In conclusion: the decomposition rate of organic matter in Northern Europe is 0.9 % per year and is thus lower than the reference value. The decomposition rate in Central and Southern Europe can be assumed to be equal to the reference value of 1.3 % per year. In this case, the 58° latitude line can be considered to be the border between Northern and Central Europe. The higher decomposition rates in Southern Europe due to higher temperatures are compensated by lower decomposition rates due to moisture deficits.

References

Boogaard, H., J. Wolf, I. Supit, S. Niemeyer, M. van Ittersum. 2013. A regional implementation of WOFOST for calculating yield gaps of autumn-sown wheat across the European Union. Field Crops Research, Vol.143, pp.130-142.

De Willigen, P., B.H. Jansen, H.I.M. Heesmans, J.G. Conijn, G.J. Velthof, W.J. Chardon. 2008. Decomposition and accumulation of organic matter in soil; comparison of some models. Wageningen, Alterra-rapport 1726, ISSN 1566-7197.