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SOILSERVICE

Conflicting demands of land use, soil biodiversity and the sustainable delivery of ecosystem goods and services in Europe

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SOILSERVICE

SEVENTH FRAMEWORK PROGRAMME

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Content

Executive Summary - SOILSERVICE

Soils and their biodiversity form the basis of agricultural production systems and generate a range of fundamental ecosystem services, such as providing food, feed, clean water and carbon storage, and control of pests and diseases. Yet soil degradation is widespread in the EU: erosion, loss of soil organic matter and compaction are some of the degradation processes that are threatening soil fertility. The SOILSERVICE project has quantified the negative impacts of intensive arable cropping systems on soil ecosystem services due to loss of soil organic matter and soil biodiversity. SOILSERVICE has also analysed how soils can be better managed to mitigate climate change and reduce nutrient and chemical inputs, and, ultimately, improve the long-term incomes of European farmers. This goes hand in hand with conserving soil biodiversity, the natural capital that generates ecosystem services. SOILSERVICE has linked ecosystem services to farmers' economic decision making by combining production, land use, soil biodiversity and sustainability in socio-economic models that can be used to analyse the consequences of current and planned policies. The findings of SOILSERVICE provide a basis for a broad range of policy decisions related to reform of the Common Agricultural Policy and environmental policy.

Intensive farming causes loss of soil biodiversity : Bacteria and fungi, nematodes, microarthropods and protozoa, and their complex interactions with each other and with plants, perform many important functions that underpin the delivery of ecosystem services. Short rotations of annual crops, high rates of fertiliser and chemical application, and absence of organic amendments (manure, grass break crops, straw, etc.) result in degradation of soil biodiversity and declining soil organic carbon content. Although impacts of land use changes may vary with regional differences in climate and soil characteristics, SOILSERVICE shows that the decrease in the abundance and biomass of most groups of soil organisms as a consequence of intensification of agriculture is general across Europe.

Restoring soils to produce more food, reduce artificial inputs and secure farm incomes: Current arable farming practices in the EU imply that soil biodiversity will continue to decline and consequently maximum yields will be lower than if biodiversity was well-maintained. Currently, inorganic fertilisers cannot substitute fully for soil services and a shift towards management that builds up soil carbon will both improve the sustainability of food production and farmers' incomes. In the four arable regions of Europe studied in the project, farmers' maximum income will increase in the future if soil carbon content—which is a good proxy for soil natural capital—is optimised. Not only do farmers benefit from higher yields but also from lower costs of inputs that are replaced by soil ecosystem services (i.e. improved fertility).

Policies based on ecosystem services: SOILSERVICE shows that most soil ecosystem services are positively correlated with soil carbon content. A single policy instrument for multiple soil ecosystem services could be based on a long term commitment to maintaining and, where desirable, increasing soil carbon content. Rewarding farmers for increasing soil carbon content would ensure cost-effective conservation of soil biodiversity but also increase farmers' profits in the future. Enhancing soil carbon content is a long-term process but it will also prevent soil erosion, loss of nutrients to surface waters, as well as promoting soil as a carbon sink to mitigate climate change. Carbon payments, if considered, could be differentiated to reflect potential spatial variation in the value of particular soil services (e.g. nitrogen retention in regions suffering from water pollution). These payments should be considered investment support and decrease over time, since increasing soil carbon is an investment in natural capital.

SOILSERVICE - context and objectives

Project context

SOILSERVICE has brought together natural scientists and economists in an inter- and trans-disciplinary approach in order to understand how competition for land use influences soil biodiversity, and sustainable provision of ecosystem goods (bioenergy, food and timber, nature) and services (clean water, control of greenhouse gases, control of pests and invasive weeds). Soils and their biodiversity are the basis of terrestrial production systems, as well as of many ecosystem services, such as delivering food, fibre, bioenergy, clean air and drinking water and carbon storage. Soil-based ecosystem services also regulate greenhouse gas emissions, reduce flooding, and prevent pests and disease. Soil biodiversity includes all soil organisms, which function in complex food webs that are fuelled by dead plant matter (detritus) and living plant roots (Wardle et al. 2004). Soil biodiversity is the foundation of the production of ecosystem functions and, as such, the delivery of ecosystem services. However, there is an urgent need to identify the linkages between biodiversity and functions in order to estimate the potential losses or gains of services resulting from different land use or climate change scenarios.

SOILSERVICE has studied ecosystem services and biodiversity in European agricultural soils in order to test and promote strategies for sustainable management of soil resources, and to mitigate degradation of soils that are under pressure from intensive land use, climate change and urbanisation. Accurate climate change projections and mitigation activities depend on models that estimate the carbon fluxes under land use and climate change. These predictions embrace processes of carbon cycling, as soils contain two thirds of total global carbon (IGBP 1998). The activity of soil organisms is pivotal for carbon cycling.

Use of soil ecosystem services in a policy context

The SOILSERVICE project has aimed to guide decisions regarding soil policies and the EU's Common Agricultural Policy, by developing tools that are based on the valuation of ecosystem services and soil natural capital in the EU. The explicit valuation of natural capital can be used to inform decision makers of the economic benefits of allocating scarce public resources towards conservation of soil biodiversity, but also the design of policy instruments that might be necessary to ensure the generation of ecosystem goods and services in socially desirable quantities (Daily, Polasky et al. 2009). Ecosystem services can be included into decision making by considering them as factors in a decision loop (Fig. 1 that has been used for incorporating natural capital into decision making (Kareiva et al 2011)

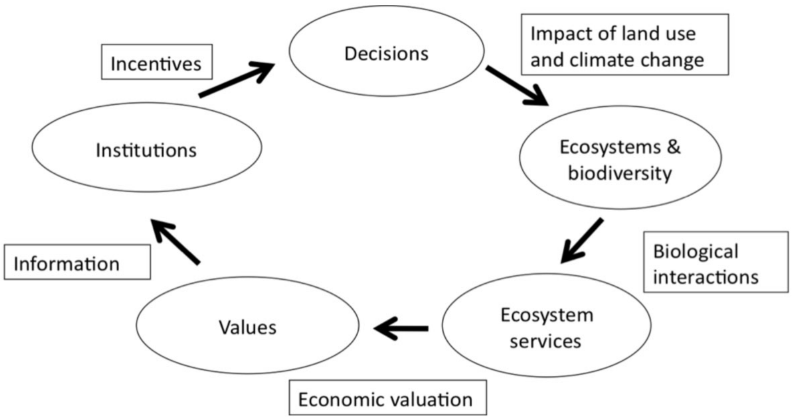


Figure 1. *after Daily et al. (2009)*

In SOILSERVICE we have developed two toolboxes: the first concerns the quantification of ecosystem services and how these are related to soil biodiversity; the second concerns valuing soil ecosystem services. These tool boxes can now be used to help decision making regarding sustainable farming in Europe.

Threats to soil biodiversity and the generation of soil ecosystem services
The greening of the European economy, which concerns the transition from fossil fuels towards bioenergy and a more biobased economy, will have strong impacts on large-scale land use, biodiversity and the sustainability of soil systems. Production of bioenergy causes major land-use changes, adding a new dimension to the traditional conflict of using land for food production *versus* land for nature conservation. Intensification of agricultural production and shifts from a crop rotation to monocultures of crops for food and bioenergy has potentially profound effects on soil biota, soil biodiversity and landscape patterns across Europe. Soils used for intensive production have faster, mostly bacterial-driven, decomposition cycles (Wardle et al. 2004) that are less efficient in storing nutrients and carbon than natural soils. In addition, current climate change is predicted to increase the frequency of extreme weather events, potentially leading to severe nutrient leaching, soil erosion and further declines in soil organic matter and soil biodiversity (IPCC 4´th Assessment Report 2007; http://www.ipcc.ch/).

Main ecosystem services under threat include:

- ***Retention of nutrients*****:** Intensification of farming may reduce the amount of organic matter in soil and the retention of plant growth-limiting nutrients (N and P), with associated increases in the transfer of nutrients to drainage waters, which causes environmental problems such as impairment of water quality
- ***Regulation of atmospheric gases*****:** The regulation of gas fluxes from soil to the atmosphere, including the production of the greenhouse gases CO_2, CH_4 and N_2O, is governed by the activity and turnover of soil organisms and is of critical importance for global change.
- ***Control of pests and invasive species*****:** Pests and exotic species worldwide are one of the major factors causing yield losses and harvest failures.

Objectives
The main objective of SOILSERVICE was to understand how economic drivers will change current and future use of soil-related ecosystem services, and how these might affect the resilience and resistance of ecological-economic systems. Specific objectives were to:

- Develop methods to value the effects of soil biodiversity on ecosystem goods and services, and compare land systems used for bioenergy, food production and nature
- Perform field and modelling studies to determine at what spatial and temporal scales soil biodiversity and soil ecosystem services are vulnerable to disturbance
- Detect processes that indicate when soil sub-systems are approaching the limits of their natural functioning or productive capacity
- Establish and improve methods to evaluate the sustainability of the ecosystem services of soils necessary for bioenergy and food production, and preservation of natural areas
- Review existing scenario studies to identify economic and social drivers that are affecting soil biodiversity and sustainable provision of ecosystem goods and services
- Interact with decision makers (farmers and policymakers) to identify threats, and develop strategies for promoting soil ecosystem services and enhancing the sustainable use of soils in the EU.

The overarching hypothesis of SOILSERVICE is that biodiversity loss is associated with declines in the complexity and functions of soil food webs, which in turn is characterised by reduced soil carbon content, nutrient retention (N and P), soil structural stability, resistance to invasions of exotic species, and increased outbreaks of pests and pathogens. SOILSERVICE has determined how losses of soil functions can be counteracted, and the resulting distribution of costs and benefits between farmers, society and future generations.

SOILSERVICE - main achievements

Approach

SOILSERVICE has investigated threats to soil biodiversity and related ecosystem services, as well as determining the economic values of these services. Biodiversity and soil ecosystem services were studied in replicated field studies with different intensities of agricultural management in across a gradient of agricultural regions and four European countries (Fig. 2): the UK (Reading), Sweden (Scania), Czech Republic (Ceske Budejovice) and Greece (Central Macedonia). Agricultural intensity ranged from pastures to intensive arable cropping with winter wheat as the crop. The regions represent different climates, as well as agricultural management being the common practice within each region. The regions are also used for valuing ecosystem services by extending economic models of farmers' economy with production functions for soil ecosystem services. This creates an ecological-economic valuation tool that can be used for evaluating current and future policies for agriculture and bioenergy production.

__Figure 2.__ Location of the four study sites

The core research of the project was organized into six workpackages (WP) that are interlinked for achieving the overarching aims of the project:

- WP1 Retention of nutrients
- WP2 Regulation of atmospheric gases
- WP3 Control of pests and invasive species
- WP4 Thresholds for vulnerability of ecosystem services and diversity
- WP5 Economic valuation of soil ecosystem services and design of effective management policies
- WP 6 Scenarios and strategies for promoting sustainable use of ecosystem services

The first three WP's have collected data on ecosystem services and soil biodiversity that are crucial for the production of food, timber and biofuels from agricultural soils. WP4 studied food web structure and functioning, and developed a theoretical framework to link soil biodiversity to soil ecosystem services using data from WP1-3. WP5 determined the value of ecosystem services provided by soil biodiversity to farmers based on dynamic production functions of soil ecosystem services, and developed economic models for policy analysis. In WP6 we investigated how soil biodiversity and sustainable delivery of soil ecosystem services are influenced by changing land use regimes; synthesized existing scenarios of future land use change, especially how the potential effects of biofuel production targets; and interacted with farmers and policymakers about how to enhance sustainable use of soils.

Soil biodiversity, food webs and nutrient retention as affected by intensive agriculture

The general aim was to study the effect of various land use intensities on soil biodiversity and nutrient dynamics on a sample of farms in Europe. The general hypothesis was that the driver intensification/extensification will affect nutrient retention, and that climate change-induced changes in rainfall patterns will alter soil biodiversity and soil nutrient dynamics. This information is needed to perform a comprehensive evaluation of the mitigation potential of proposed changes in land use for sustaining soil fertility.

Soil biodiversity and food webs negatively affected by intensive agriculture

SOILSERVICE results in Fig. 3 show the effects of three levels of increasing intensity (as represented by the crop rotations *pasture – extensive rotation – intensive rotation* that are typical within the regions) on the number of functional groups in the food web, as well as the diversity within soil fauna groups (i.e. *Earthworms*, and the small micro arthropods *Oribatid mites* and *Collembola*). The foodweb and fauna groups are all shown to decrease significantly with increasing intensity. Importantly, even though soil biota and their activities are responsive to regional climatic and soil types, land use intensity had a general negative impact on functional group diversity of soil biota across the four countries.

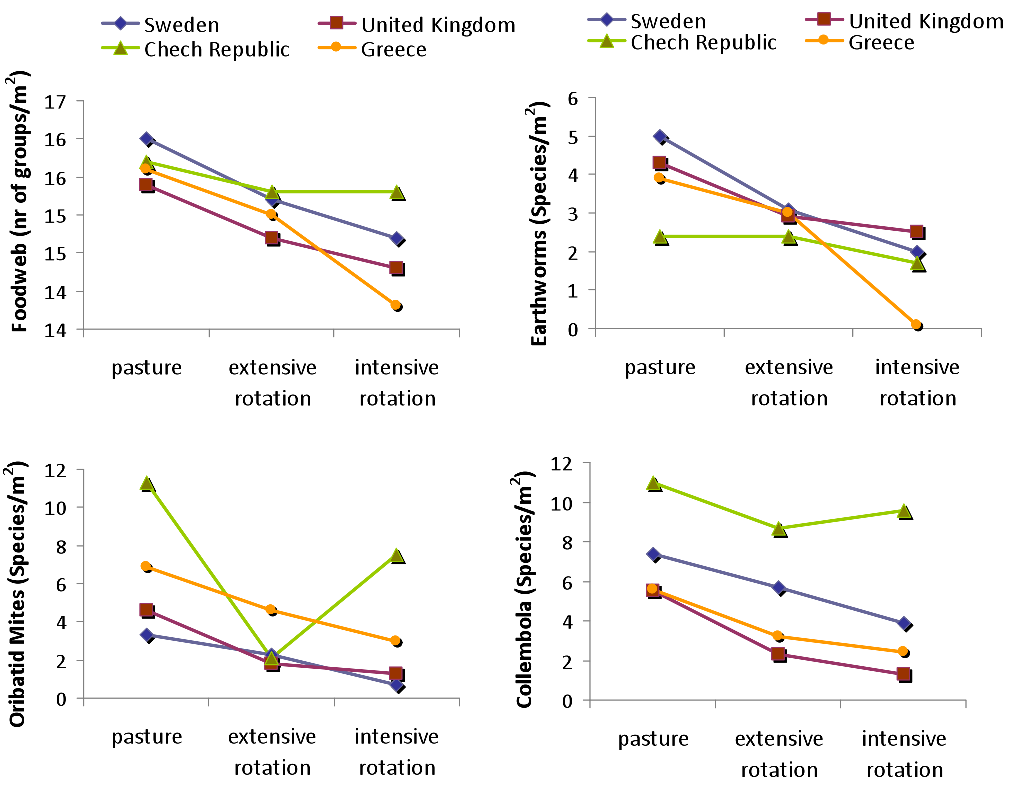


Figure 3. *The decline of functional group diversity of soil biota (upper left panel), and numbers of species of; Earthworms (upper right panel), Oribatid mites (lower left panel) and Collembola (lower right panel) due to increasing land use intensity in the four study regions (Tsiafouli et al. in preparation).*

Some groups within the food web in the intensively managed soils are missing and the others have smaller biomass than in pasture webs. It is seems that land use intensity does not appear to affect all functional or taxonomic groups in the same way. Some groups like bacteria and their consumers (bacterial feeding nematodes and amoeba) are even favoured, at least in quantity but not necessarily also in diversity. Soil tillage has a particularly large negative effect on groups that have a limited ability for dispersal and re-colonisation such as earthworms and arbuscular mycorrhizal fungi (Curry et al. 2002). Fig. 4 summarizes how increasing land use intensity leads to a decline in biomass in some trophic groups as well as the loss of groups and feeding links among the groups in the soil food web. A more detailed study on the nematode community showed that their metabolic footprint (as defined by Ferris et al. 2010) decreases with increasing land use intensity (Tsiafouli et al. 2011).

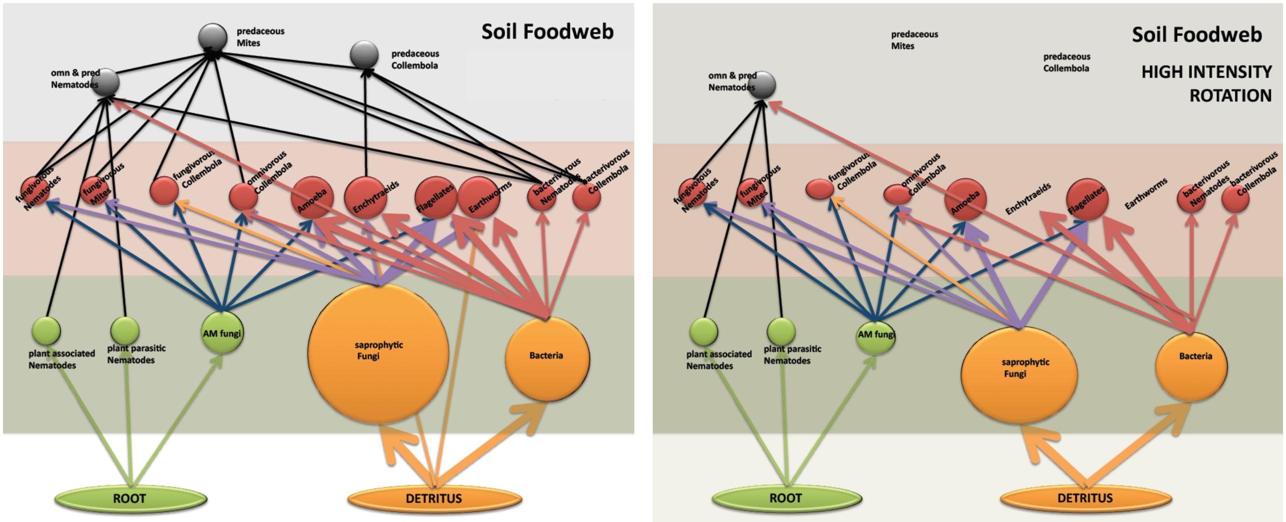


Figure 4. *Soil food web composition as affected by land use; pastures (left) and intensively managed wheat fields (right). Circle size indicates the biomass of the group, and arrows represent feeding links between groups.*

Conclusions: Intensive management of agricultural systems has a negative impact on the quantity (i.e. biomass and abundance) of most soil organisms, but also their taxonomic diversity and diversity of relations (i.e. links) to other species or groups, thus affecting the overall structure of the soil food web.

Links between soil food webs and nutrient retention

To test the implications of reduced food web complexity on the delivery of soil-based ecosystem services, we analysed the relationships between soil food web structure and the processes of carbon and nitrogen loss across the SOILSERVICE sites in Europe. Soil food webs can be characterised as either fungal-based or bacterial-based (Fig. 5). Fungal-based soil food webs have lower N losses through leaching (De Vries, Van Groenigen et al. 2011). In addition, they could contribute more to soil carbon sequestration than bacterial-based soil food webs (Six, Frey et al. 2006).

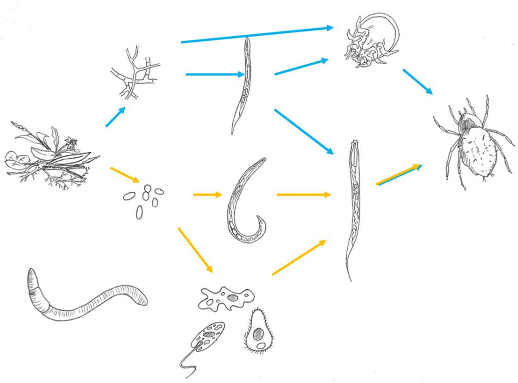


Figure 5. *The soil food web; showing fungi and bacteria at the base, the fungal decomposition pathway (blue arrows) and the bacterial decomposition pathway (yellow arrows).*

SOILSERVICE found that especially the organisms that form the fungal-based pathway (i.e. the chain of organisms that feed on fungi) are vulnerable to intensification of agriculture (Fig. 6), with significant declines in arbuscular mycorrhizal fungi (AMF) with intensification.

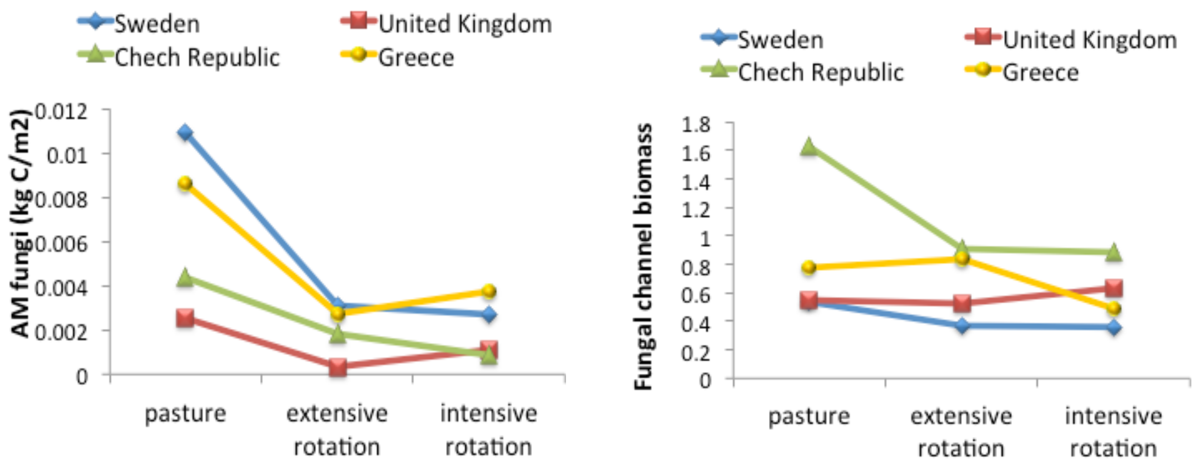


Figure 6. *Impacts of agricultural intensification on arbuscular mycorrhizal fungal biomass, and the biomass of the fungal energy channel.*

SOILSERVICE results show that the rate of nitrogen mineralisation, a measure of the production of a crucial nutrient for plant growth, increased with greater biomass of organisms in the bacterial energy channel. Excessive mineralization can result in leaching and cause environmental problems. Importantly, we found that nitrogen leaching decreased with increasing biomass of AM fungi, which are part of the fungal energy channel (Fig 7).

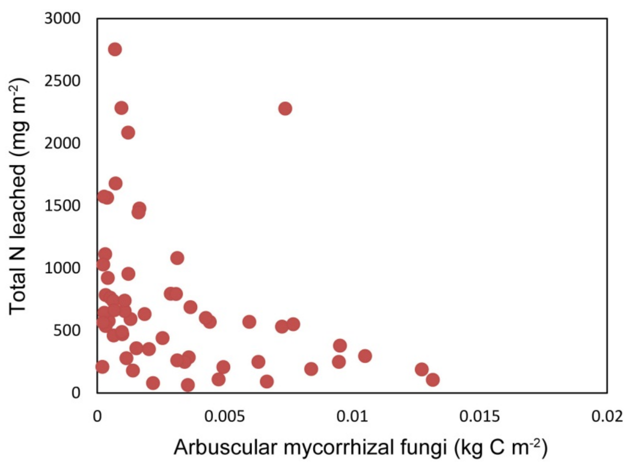


Figure 7. *Negative relationship between AM fungi and nitrogen leaching from soil, across four sites in Europe (P = 0.004).*

The incidence of drought is expected to increase with climate change. In a greenhouse experiment with experimental drought periods, we found that the soil food web in extensively managed grassland soil was more resistant to drought than the soil food web in intensively managed wheat. Moreover, the soil food web in pastures continued to perform its functions better under drought than that of wheat, and we found that this was directly linked to the composition of the soil food web: a greater importance of the fungal energy channel (higher F/B channel ratio) mitigated carbon loss as respiration from soil, and a greater microbial diversity (PLFA evenness) reduced the amount of nitrogen leached from the soil (Fig. 8) (De Vries, Liiri et al. 2012).

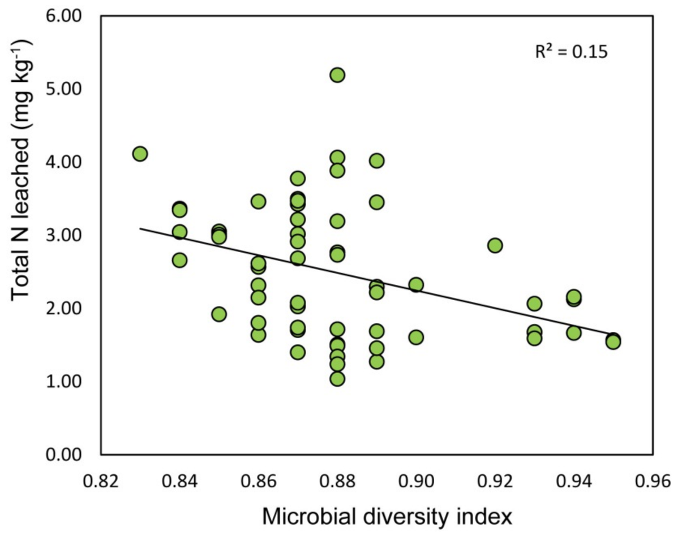
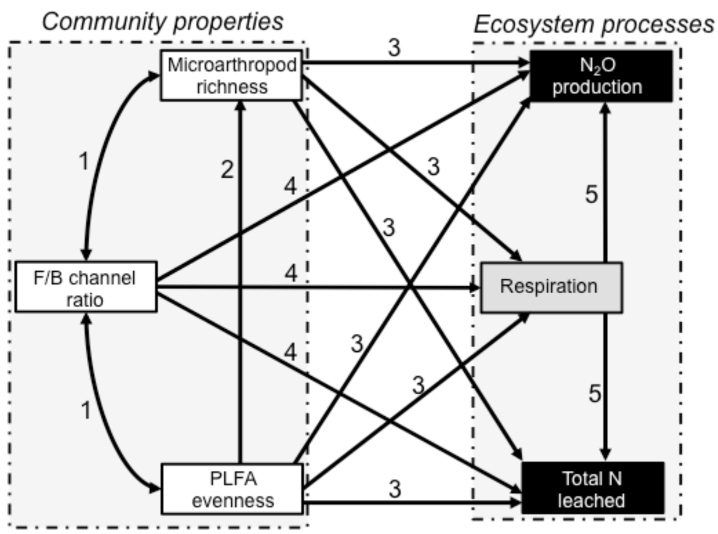


Figure 8. *Negative relationship between soil microbial diversity and N leaching.*

We used a model to analyse the relationships between soil food web structure and losses of carbon and nitrogen (Fig. 9). The model showed that an increase in the F/B channel ratio, a measure of the relative abundance of fungi to bacteria, reduced the amount of carbon lost from the soil, and a higher microbial diversity (PLFA evenness) explained reduced nitrogen leaching. In addition, greater microarthropod richness stimulated nitrogen leaching when the soil food web had recovered from drought (De Vries, Liiri et al. 2012). These findings indicate that soil food web structure, which is strongly affected by land use, directly controls ecosystem processes. The results of the greenhouse experiment were also confirmed in a field experiment as the ability of soils to retain nitrogen was reduced by drought in wheat fields, but not in grassland soils, indicating increased risk of nutrient leaching from intensively managed land after extended periods of summer droughts.

Figure 9. *Mechanistic links between soil food web composition and losses of C (respiration) and N (N_2O production and total N leached) from soil. Shared causal influences and direct interactions within the food web. 1, Bottom-up trophic effects; diversity in food sources leads to diversity in consumers; 2, Biodiversity positively influences ecosystem function via complementarity. 3, Fungal and bacterial energy channels exhibit distinct impacts upon ecosystem functions; 4, Fungi are more effective N scavengers; 5, Overall microbial activity regulates N-cycling. From De Vries et al. (2012).*



Conclusions: We found in both the field sampling across Europe, as well as in greenhouse experiments, that the fungal energy channel was correlated to lower nitrogen leaching losses from soil. This suggests that promoting fungal-based soil food webs would enhance soil nitrogen retention, preventing nitrogen in the soil from being leached and delivering it to the plant, for instance through associations of AM fungi with plant roots. There is a range of management options to reduce nitrogen losses from soils by promoting fungal-based soil food webs, although most of these options result in reduced crop yield (Table 1). In addition, fungal-based soil food webs have many more benefits, as they are more resistant to drought and lose less carbon as a result of drought, and AM fungi can enhance resistance of crops against soil-borne and some foliar diseases (Elsen, Gervacio et al. 2008). It has also been proposed that ecosystems dominated by fungi are less vulnerable to invasions of exotic species than bacterial-based systems with high nitrogen availability (van der Putten, Klironomos et al. 2007).

	Total N leaching	DON leaching	Denitrification	N_2O/N_2 ratio	NH_4^+ volatilization	Yield	References†
Cessation of liming	↓	↓	↓	↑	↓	↓	Baggs et al. 2010, Burton and Prosser 2001, Clough et al. 2003, Haynes and Naidu 1998, Jiang and Bakken 1999, Kemmit et al. 2005, Kemmit et al. 2006, Sommer and Ersbol 1996
Reduced N inputs	↓	↘	↓	→	↓	↓	Constantin et al. 2010, Cuttle and Scholefield 1995, De Vries et al. 2006, De Vries et al. 2011, Huang et al. 2011
Reduced tillage	↓	→	↗	↗	→	↘	Ball et al. 2008, Constantin et al. 2011, Jackson et al. 2003, Vinten et al. 2003
Manure instead of fertilizer	↘	↗	↑	↑	↑	↘	Bittman et al. 2005, Jiao et al. 2004, Korsaeth et al. 2003, Stark et al. 2006
Timing of management*	↓	→	↓	→	→	↑	Cuttle and Scholefield 1995, Eriksen et al. 2004, Vinten et al. 2002
Catch crops, green manure	↓	→	↓	→	→	↘	Constantin et al. 2011, Herrera et al. 2010, McSwiney et al. 2010
Biochar amendment	↓	?	↓	?	?	→	Augustenborg et al. in press, Ding et al. 2010, Laird et al. 2010, Major et al. in press, Spokas et al. in press, Jones et al. in press
Clover seeding or rotation#	↘	→	↑	→	→	↑	Cuttle and Scholefield 1995, De Vries et al. 2006, Drinkwater et al. 1998, Pappa et al. 2011, Stark et al. 2006

* Fertilization and tillage
\# Including intercropping
† See WebReferences

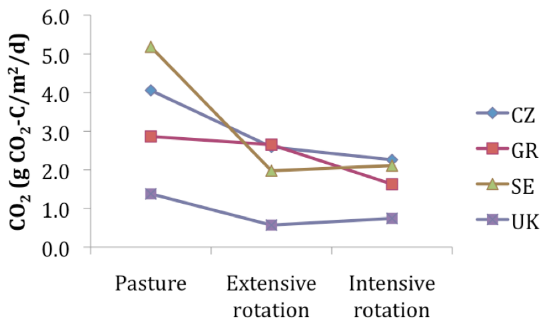
Table 1. *Management options for promoting fungal-based soil food webs and plant-microbial linkages, and their consequences for N loss pathways and yield. Horizontal arrows indicate either no effect, or contrasting effects found in the literature; upward arrows indicate an increase; downward arrows indicate a decrease. The darker green the colour of the cells, the more important the role of soil microbes and plant-microbial linkages; white cells indicate either no role for these, or insufficient information in the literature. From De Vries and Bardgett (2012).*

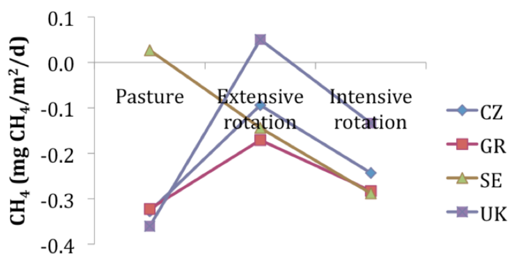
Regulation of atmospheric gases

The general aim was to study the effect of soil biodiversity at various land use intensities on gas exchange between soil and the atmosphere. Intensification of agriculture will affect the exchange of CO_2, CH_4, and N_2O between the biosphere and atmosphere, however there is no clear picture of the role of soil biodiversity in the responses of gas exchange to alterations in soil management intensity. This information is needed to perform a comprehensive evaluation of the mitigation potential of proposed changes in land use for greenhouse gas production.

Gas exchange in the field in four countries

The balance between organisms producing and consuming nitrogen compounds governs whether they pollute surrounding air and water. Soil management plays a central role in governing conditions for soil organisms and therefore whether unwanted gas exchange occurs. In SOILSERVICE, we have measured the production of greenhouse gases at three different intensities of farming at the field sites of all four regions. Release of N_2O to the atmosphere was most frequently observed with extensive crop rotation in all four regions. Emission of N_2O from soils to the atmosphere is an intricate balance between nitrogen not immobilised by soil organisms and plants, but is also dependent on the oxygen and carbon levels in the soil. With lack of oxygen denitrification can be complete and inert N_2 (nitrogen gas), will be produced. Uptake of N_2O from the atmosphere into the soil occurs with the same organisms that otherwise release N_2O to the atmosphere. This means that soil biological processes can change a site from a green house gas source to a sink. The SOILSERVICE results indicate that pastures, can act as a sink for N_2O.





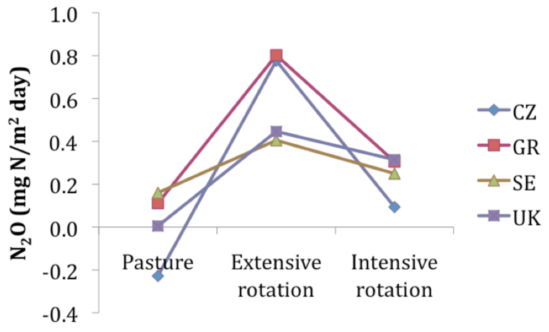


Figure 10. *Gas flow of CO_2, CH_4, and N_2O between the soil and the atmosphere. Positive values indicate release from the soil whereas negative values indicate that the soil is immobilising gas from the atmosphere.*

CO_2 release is a product of the carbon turnover of the soil organisms and the highest release rates were from the pastures where biological activity is expected to be the highest among the three land-use intensities (Fig. 10). The general pattern for CH_4 is absorption that is seen in the intensive rotations and pastures. The pattern of N_2O exchange was unexpected as the extensive rotation shows higher release from the soil than the intensive rotation and pasture. In the extensive and intensive crop rotations, nitrate availability is probably sufficient for N_2O release and the higher release in extensive rotation is most likely due to a larger occurrence of anaerobic soil volumes – required for N_2O production – with many easily decomposable crop residues. The low N_2O release in the pastures, even giving N_2O absorption in some cases, is likely due to low amounts of soluble soil nitrate due to efficient uptake from the vegetation. In a pasture soil organisms with the ability to produce N_2O may instead convert this gas into N_2 which is harmless compared to the greenhouse gas N_2O.

Climate change effects

Climate change is expected to cause larger drought events as well as more frequent heavy rains. Assessing the impacts of summer drought was done by using roofs in the fields to prevent rainfall during the crop growth period. This can help us to understand how nitrogen is mobilised by microorganisms during periods of drought, which are predicted to increase.

The field experiments with a simulation of summer *drought* resulted in lower biological activity in the soil and consequently reduced CO_2 release (Fig. 11). CH_4 absorption remained fairly constant or increased due to drought in the pasture soils, but was lower in the intensive rotation soils. N_2O absorption, which generally prevails in pastures, declined as a result of the drought, whereas N_2O absorption increased during drought in the intensive rotation soils (in particular in the UK). As mentioned above, changes in N_2O exchange are very much dependant on the distribution of oxygen-free (anaerobic) locations in the soil combined with the availability of nitrate. Drought reduced the frequency of anaerobic conditions in the soils and also N_2O absorption in pasture soils.

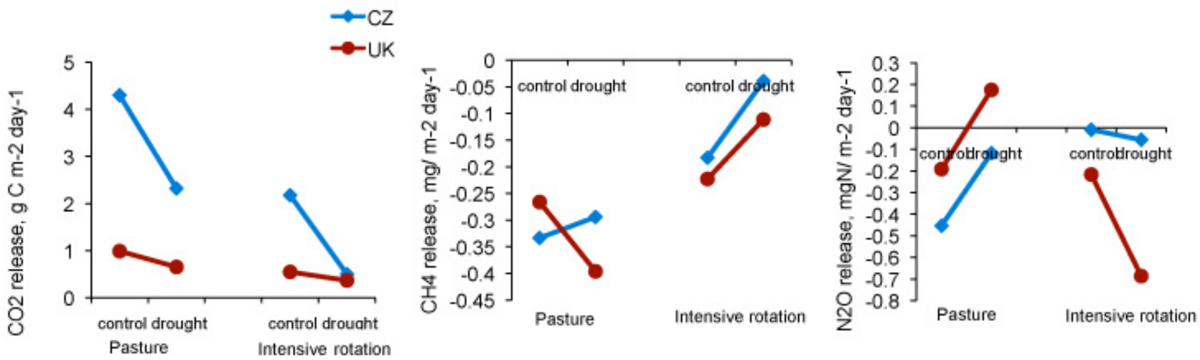


Figure 11. *Effect of drought on gas exchange, average of three farms in Czech and UK.*

Extreme weather events and soil ecosystem services at risk

Additional simulations of repeated drought and rewetting of sampled soils were conducted in a laboratory. The rewetting experiment resulted in relatively large amounts of CO_2 being released from the intensive rotation soils (Fig. 12-a) and relatively less released from the pasture soils (Fig. 12-b). The associated increased in biological activity means more oxygen consumption and thereby creation of oxygen-free soil where N_2O may be produced based on the massive release of nitrate due to drought. This phenomenon is particularly pronounced in the pasture soils (Fig. 12-d) where a high soil organic matter content promotes the process compared to the intensive rotation in which case the pulse of N_2O release was not observed (Fig. 12-c)

Conclusions: Extreme weather events, which are predicted to occur more often in the future, may result in soils that normally generate a high level of ecosystem services, rapidly shifting to soils with very poor generation of ecosystem services.

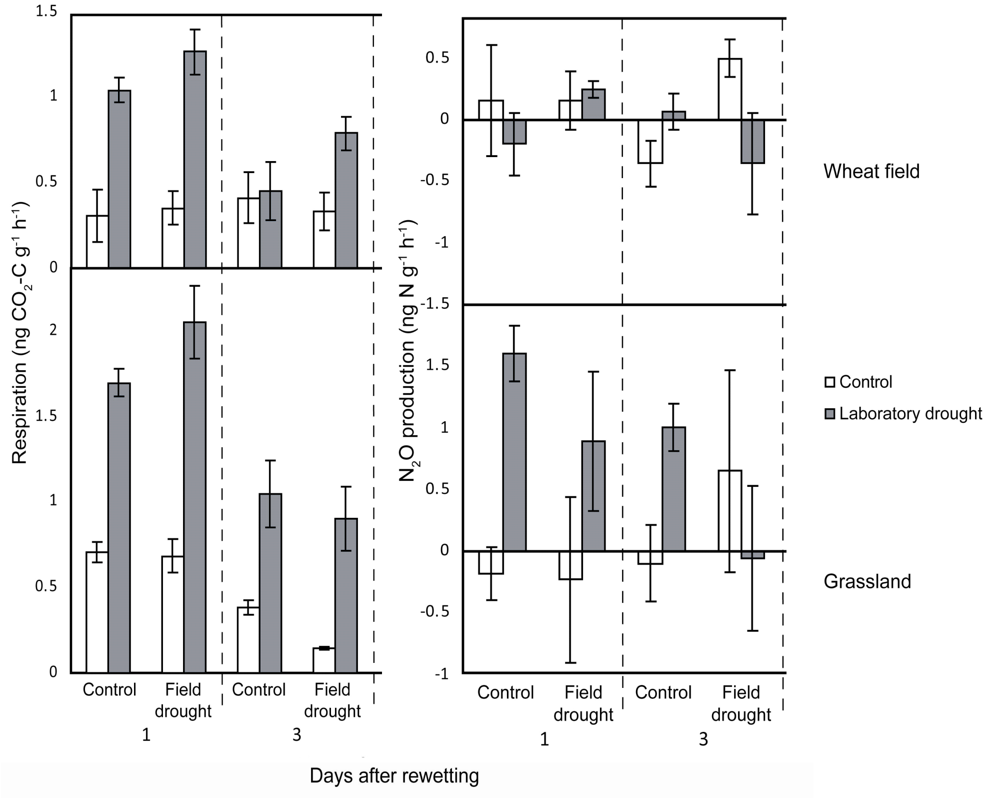


Figure 12. *Effect of repeated rewetting in a laboratory on exchange of CO_2 (a,b) and N_2O (c-d) on soil that experienced drought in the field and soil that did not (control) for two intensity gradients; wheat field (top) and grassland (bottom).*

Importance of soil biodiversity for gas exchange

Soil samples from the different farming intensities were reduced artificially in the microbial diversity. The soil was put in pots and placed in the greenhouse with winter wheat. We found a higher frequency of extreme values of N_2O exchange, either very high emissions or absorption of the gas from the atmosphere, at low diversity compared to high diversity.

Conclusions: Intensive farming can induce shifts in soil ecosystem services, from being negative when CH_4 or N_2O is emitted, to positive when these gases are absorbed by the soil. In the case of N_2O, this shift does not even require changes in land-use, subtle changes in nitrate availability resulting from different management of fertilisers and crops can change the sign of the soil service between positive and negative. We show that less numerous organisms are important for the functioning of the soil with respect to trace gas exchange. The shift of N release to the atmosphere as N_2O can have as large an impact on the environment as the release of N in leachates to surface water.

Control of pests and invasive species

The general aim was to determine the relationship between land use, soil biodiversity and the control of pests and invasive species. The general hypothesis is that when reducing plant and soil microbial diversity, crops and natural ecosystems are more vulnerable to attacks by pests and pathogens. The results achieved will help to better understand the relationship between soil biodiversity and pest control.

Pests and exotic species worldwide are one of the major factors causing yield losses and harvest failures. Pests and exotic species also occur in natural ecosystems; however, some natural systems exert an amazing capacity to control pests (Van der Putten 2005) and exotic plant species (Klironomos 2002, Reinhart et al. 2003, Callaway et al. 2004) by interactions between plants, pests and their natural enemies. This capacity to control is called biotic resistance. Achievinge biotic resistance in arable soils is one of the holy grails of modern agriculture, whereas intensified land use, e.g. driven by increasing biofuel production, may cause a major loss of biotic resistance. Intensive land use (ploughing, fertilizing, pesticide use) is putting heavy selection pressure on soil organisms and is expected to reduce soil biodiversity. If the lost species were important for the control of pests and invasive species, then land use intensification will increase the vulnerability of crops to pests and weeds.

The effect of land use on control of pests and weeds

The *first aim* was to determine whether land use indeed changes the ability of soil to control pests and weeds. Soil from fields under the three SOILSERVICE land use intensities were brought into greenhouses, and pests and weeds were added to test the capacity of soil to control pests and weeds under controlled conditions. Wheat planted to the soils sampled from the different management intensities at each site were exposed to aphids. Aphids are very sensitive to plant quality and could thus be expected to respond to the soil organisms via changes induced in the plant. Initially aphid infestation was slightly higher in plants on soil from grasslands, but there is no evidence that soils from different land use intensity differ in the capacity to control aphids.

To test the relationship between land use and weed control, several phases of the weed growing cycle were examined (germination, growth and competition). The germination experiment gave no indication that less intensive management would improve biotic resistance against weeds. Weed biomass, however, was lower in the soils from the grassland soils. When we look at competition between a crop and weeds, wheat plants from the intensive crop rotation soil suffered less from weed competition than plants from medium and low management intensity. Overall, the experiments show no consistent results for the effect of land use intensity on different aspects of weed control.

Soil biodiversity and control of pests and weeds

Soil microbial diversity provides many ecosystem services. Soils are extremely species rich and little is known about the consequences of diversity loss. Soils contain a mix of beneficial, neutral and harmful species. Communities with higher diversity are expected to be more resistant to invasions. Our *hypothesis* is that conserving soil biodiversity will prevent loss of beneficial soil microorganisms, and consequently prevent an increase of harmful soil microorganisms. In SOILSERVICE the consequences of microbial species loss were studied under controlled circumstances in a laboratory (Fig. 13). The effects of microbial species loss on plant growth varied with land use intensity. Grassland soils were more likely to lose beneficial species, and tended to have lower biomass production after microbial species loss. Soils from the extensive and intensive rotations were more likely to lose harmful organisms, since plant growth increased with soil species loss.

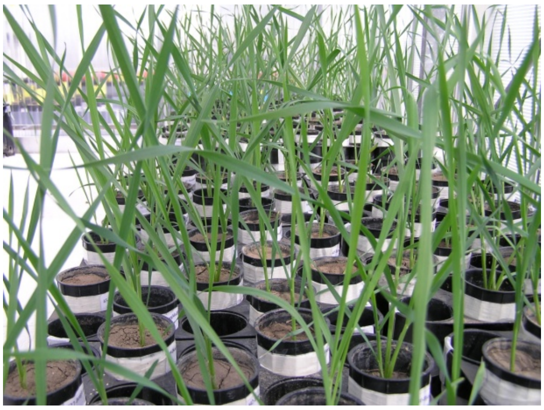


Figure 13. *Wheat plants in a greenhouse experiment using soil from grassland and intensively cropped arable fields to examine the consequences of losing species.*

Adding biochar for soil recovery: effects on control of pests and weeds

We tested the effect of adding carbon in the form of biochar to soils. Biochar is a waste product from biofuel production that is thought to improve soil fertility by increasing soil carbon levels, although experimental tests of this are scarce. In a greenhouse experiment, we tested how addition of biochar affected plant growth and soil organisms such as nematodes and protozoa. We tested the *hypothesis* that biochar addition would change the soil community composition with beneficial effects on plant growth. Plants growing on soil from biochar plots had less plant biomass, especially when soil biodiversity was reduced. Biochar addition appeared to have a minor negative effect on plant biomass, possibly due to a reduction in the number or effectiveness of mutualists. Plant parasitic nematode numbers increased in soil without biochar. Plants without biochar were more likely to flower than plants with biochar (Fig. 14). Thus, our results suggest that biochar could negatively impact plant growth or phenology. However, longer term field research is needed to test whether the use of biochar can be optimized to stimulate target plant species and inhibit unwanted plant species such as invasive weeds.

Figure 14. *Biochar addition to soils seems to delay flowering of Medicago sativa*

Conclusions: How to prevent the risks of microbial species loss and increased abundance of pest? There are several options. For example, managing soil organic matter will promote soil biodiversity, so that unwanted microbes may not be able to develop in high numbers. Another possibility is to reduce soil disturbance to a minimum when managing soils.

Economic valuation of soil ecosystem services

The general aim was to value ecosystem services provided by soil biodiversity to the farmer, which was done for a gradient of high-yielding arable cropping regions in the EU. This work has simultaneously resulted in the development of a toolbox of methods for valuing soil natural capital and associated flows of ecosystem services. In our approach soil organic carbon (SOC) serves as a proxy for the stock of soil capital. Production functions were estimated from long-term data to quantify the joint effect on crop yield of SOC concentration and fertilizer input. The production functions were subsequently integrated with traditional economic models to value soil natural capital and with an agent-based model (AgriPoliS) for policy analysis. The extended AgriPoliS model was used to analyse the potential impacts of the CAP2013" greening" proposal on soil services.

Managing Soil as Natural Capital Natural

Natural capital is receiving increasing attention as both a concept and framework for valuing natural resources (Dasgupta 2010; Kareiva, Tallis et al. 2011). Soil natural capital—the power of a soil to generate sustained flows of ecosystem services—is an essential input to agriculture (Daily 1997; Dominati, Patterson et al. 2010). The most obvious service provided by soil capital is crop yield, which in turn is supported by services, such as carbon and nutrient cycling, water holding capacity and soil fertility (Barrios 2007). Maintenance of these supporting services can be crucial for the sustainability of agriculture (Brussaard, de Ruiter et al. 2007), but also for general human well-being via, for instance, carbon sequestration, water purification and flow regulation, nutrient retention, regional climate and air quality regulation, etc. (Smith, Powlson et al. 1997; Foley, DeFries et al. 2005).

Production functions to quantify flows of soil ecosystem services

To quantify the impact of soil natural capital on crop yield and the need for artificial fertiliser we estimated agricultural production functions (Cerrato and Blackmer 1990; Frank, Beattie et al. 1990). Since soil organic carbon (SOC) is both the habitat and resource for most soil organisms, it was used as a proxy for the stock of soil natural capital. To estimate the functions we obtained data on the yield (kg ha^{-1}) of winter wheat for different levels of fertiliser application (N kg ha^{-1}) and varying stocks of SOC (%C) from some of the world's oldest running agricultural experiments: A) *Askov* in Denmark; B) *Broadbalk* at Rothamsted in the UK; C) *Bad Lauchstaedt* in Germany; and D) *Scania* in Sweden. The general results are illustrated in Fig. 15, where yield is shown to increase with fertiliser application up to the level of optimal fertiliser input, i.e. the minimum fertilizer needed to achieve the maximum yield associated with a particular level of SOC (Frank, Beattie et al. 1990). Similarly, yield increases with SOC (up to the optimal level, not shown) (Lal 2010).

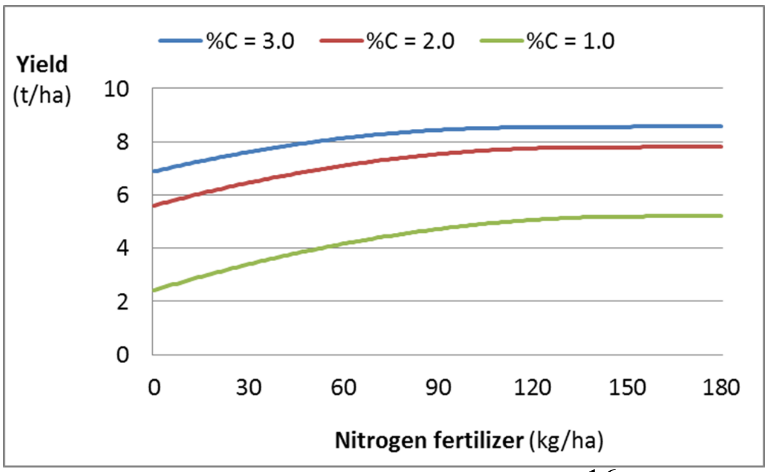


Figure 15. *Yield response of winter wheat to artificial fertilizer N application for increasing concentrations of soil organic carbon (%C)*

As the production functions include a measure of soil natural capital (%C), it was possible to determine the impact of a marginal change in soil capital (±1%) on yield, optimal fertiliser input and annual farm profit which are given in ***Table*** . The impact on yield and profit is positive (Table 1), but in addition the need for artificial fertiliser declines. Further, when moving from the highest SOC to the lowest SOC concentration measured at each site, the maximum yield falls by: 7% for Askov; 20% for Broadbalk; 28% for Bad Lauchstaedt; and 50% for Scania. This demonstrates that fertiliser can only partially substitute for services generated by soil organisms, and hence the necessity to increase the rate of fertiliser input to achieve a particular yield at lower levels of SOC.

Table 2. *Changes in flows of ecosystem services and farm profits due to a 1% relative change in the stock of soil natural capital (i.e. %C) where Δ indicates change*

	Today	**ΔSOC**	**ΔFert N**	**ΔYield**	**ΔProfit**
Site	%C	%C	kg/ha/yr	kg/ha/yr	€/ha/yr
Askov	1.26	.013	0	15.47	2.32
Broadbalk	1.08	.011	-0.18	7.76	1.36
Lauchstaedt	1.87	.019	0	37.87	5.68
Scania	1.70	.017	-0.30	38.23	6.06

Conclusions: To achieve the maximum possible yield *both* SOC and fertiliser input need to be optimized. For example, in Scania optimal fertiliser application produces 75 kg wheat kg^{-1} N when SOC is 3.4% but only 28 kg when it is 0.8%. Any deviation from the optimum implies that too little food is being produced with too much fertilizer. It follows that future farm profits would also be less than possible. Since artificial fertiliser causes substantial environmental impacts, these results also have implications for mitigation of agriculture's environmental impacts.

The value of soil natural capital to arable farmers in the EU

SOC conservation decisions (i.e. whether to invest in natural capital) should be based on how much an incremental or *marginal* change in soil capital will influence flows of ecosystem services, and, in turn, future profit. Just as the unit prices of alternative crops convey critical information for determining which crops to grow, it is the marginal value or shadow "price" of soil capital that is the key to improving natural resource decisions (Daily, Polasky et al. 2009). To do this we calculated the present value (PV) of the change in future profit (i.e. **ΔProfit** in Table 1) at each site*,* brought about by a marginal change in soil capital (i.e. **Δ**SOC), as a perpetual annuity such that $PV = \Delta\pi(1+\delta)/\delta$ where δ is the discount rate (e.g. Polasky, Nelson et al. 2008). Consequently, the valuation of natural capital contains, unavoidably, an objective part—the change in annual profit—and a subjective part—the choice of discount factor.

Conclusions: The marginal natural capital value of SOC was found to be (in € ha^{-1}): Askov **80**, Broadbalk **47**, Lauchstaedt **195**, and Scania **208** for a social discount rate of 3% (NB: the results are highly sensitive to the discount rate (Weitzman 2007); a lower discount rate would result in higher values and *vice versa*). Clearly, the value of soil as natural capital is significantly higher than the myopic static analysis indicates (i.e. Table 1).

Agent-based modelling of farming and soil ecosystem services

To model the effects of soil ecosystem services on agricultural production and farm profits we extended the agent-based AgriPoliS model (Happe, Kellermann et al. 2006) with production functions that model yield response to fertiliser input and spatially explicit SOC (and hence soil ecosystem services).The extended model also considers the effect of changing SOC on economic optimal inputs of nutrients (P and K) and chemicals, making it possible for farm-agents to substitute between external inputs and ecosystem services. The model was calibrated to the South-East region in the UK and Scania in Sweden. These empirical models can now be used to evaluate the effects of policy on farmers land use decisions and concomitant flows of soil ecosystem services 25 years into the future.

The models were used to evaluate the effects of the "greening" proposals in the CAP 2013 reform. A major part of this reform is the obligation to create *ecological focus areas* amounting to 7% of a farm's agricultural area, which, for modelling purposes, we interpret as grass sown fallow land. In Table 3 we present the long-term effects of the reform on the profitability of the major crops grown in each region if the grass fallow is included in the crop rotation at 7% (the minimum obligation), 15% or 25% (an area consistent with green manure needs in livestock free organic systems) of the farmed area compared to continuing with current practices (i.e. 0% fallow). Over time, continuing with current practices results in declining gross margins due to declining SOC and an increasing need to substitute artificial inputs for soil ecosystem services. This effect is, however, alleviated by the reform, since the introduction of grass fallow reduces rates of SOC decline. At 25%, the loss of SOC is almost eliminated, and hence the reduction in gross margin. As such, the reform could improve the sustainability of arable crop production in the EU; but only if grass fallow is rotated with annual crops. Obviously a permanent fallow would only benefit soil that is no longer used in crop production and hence would not improve the sustainability of land in agriculture.

Table 3. *Relative changes in gross margin 2012 to 2032 due to alternative proportions of ecological focus areas*

Crop	Region	GM[a] 2010 €/ha	Scenario — Proportion of ecological focus area: 0%	7%	15%	25%
Wheat	*Sweden*	687	-8%	-6%	-4%	-2%
	UK	535	-3%	-3%	-2%	-1%
Rapeseed	*Sweden*	589	-14%	-11%	-8%	-4%
	UK	429	-12%	-11%	-8%	-3%
Sugarbeet	*Sweden*	1194	-23%	-17%	-12%	-6%

[A] Gross margin in base year

In contrast, farm profit per hectare increases in all scenarios in Sweden and the UK, (Fig. 16). This is because structural change over the period results in declining labour and capital costs per unit area, which are sufficient to outweigh losses in soil ecosystem services. Notice, however, that the relative differences in profits between scenarios decrease over time. This is because in the scenarios with grass fallow (7-25%), soil ecosystem services increasingly replace external inputs, and yields per unit fertiliser input also increase over time. In the long run it seems—according to our assumptions— that augmenting soil ecosystem services can fully compensate for the drop in profit resulting from putting land into fallow (seen by extrapolating all trends). As such the current costs of putting land in fallow should be treated as an investment in soil natural capital that will produce significant benefits for future generations.

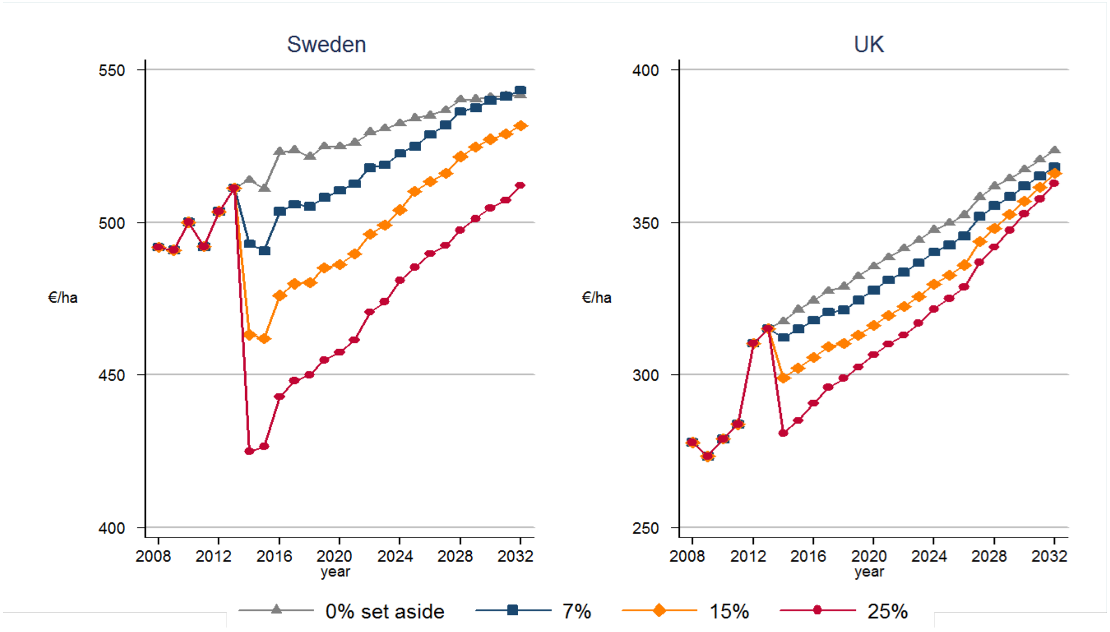


Figure 16. *Developments in profit per hectare over time in Sweden (left) and the UK (right)*

Conclusions: The benefits to farmers of conserving soil biodiversity were found to occur quite far into the future (10-20 years), and hence it is very costly in the short-term for farmers to adopt socially desirable conservation measures (Fig. 16). Further, services such as carbon sequestration are a public good and this value is not being considered by farmers in their soil management decisions. Consequently, there is a strong case for policy intervention in the management of intensively farmed European arable soils. Two complications need to be considered in the formulation of policy. First, soils constitute natural capital that can only be built up over time; hence policy must have a long-term perspective similar to that of investing in infrastructure. Second, since soils generate multiple services, policy should target a variable that is highly correlated with all services; soil carbon content would be ideal. Policy alternatives are suggested below.

Perennial biofuel crops and soil organic matter

The aim of this study was to investigate whether incorporating perennial biofuel crops in arable crop rotations would improve soil organic matter content, reduce nitrogen leaching and CO_2-emissions, and thereby contribute to more sustainable agricultural soils. The study was done in existing perennial biofuel crops, specifically; willow, Miscanthus grass, Phalaris grass and poplar, in the UK, Czech Republic and Sweden, and involved measuring a range of soil properties as affected by the biofuel crop.

Potential benefits of perennial biofuel crops

The potential of perennial biofuel crops to reduce greenhouse-gas emissions and to improve sustainability of agricultural soils has received much attention (Zan et al. 2001, Rooney et al. 2009, Davis et al. 2012). Perennial biofuel crops have been demonstrated to contribute to sustainability of agricultural land by increasing soil carbon, and thereby reducing erosion, leaching and compaction (Fazio and Monti 2011). However, the environmental effects of biofuel crop cultivation depend on both the crop and type of soil the crop is grown on, hence a more science-based accounting system of the costs and benefits of biofuel production has been called for (Dale et al. 2010). The suggested benefits of biofuel crops may also be a way to overcome the risk that farmers experience when planting a long-term, perennial crop (Ericsson et al. 2009). Suggested benefits are reduced nitrogen leaching (Davis et al. 2012), increased carbon sequestration (Rooney et al. 2009) and reduced erosion (Hartman et al. 2011). We analysed factors important for soil ecosystem services in order to evaluate added values of perennial biofuel crop cultivation.

Effects on soil organic matter

We found that soil organic matter did not increase with cultivation of perennial biofuel crops (i.e. willow, energy grasses or poplar), (Fig. 17). Both saprophytic fungi and arbuscular mycorrhizal AM fungi increased after 10 years of willow (Fig. 17), while there was no significant increase in poplar (data not shown). The most significant increase in AM fungi was found in *Phalaris* plots in Sweden while this was not visible in Czech Republic (data not shown). *Phalaris* cultivation did not affect saprophytic fungal or bacterial biomass. Soil respiration (g $CO_2 \times m^{-2} \times d^{-1}$) was lowest in new willow cultivation and highest in *Phalaris* energy grass (Fig. 18).

Soil organic matter content at our study sites was not affected by biofuel crop cultivation, not even after ten years of cultivation of willow. Since short rotation coppice plantations have been suggested to promote overall soil sustainability as well as carbon sequestration in agricultural land (Grogan et al. 2002, Jordan et al. 2007), we had expected soil organic matter to increase over time in the willow and poplar plantations. One reason for not detecting an increase in soil carbon might be that roots were sieved out of the soil prior to carbon analysis and that soil samples were taken in standing plantations. Samples from terminated plantations might show higher measurements of soil organic matter due to decomposition of dead roots and other organic matter left in the field after harvest. In addition, we only analysed samples from the top 15 cm of the soil, while increased soil organic content could be expected deeper down in willow plantations (Zan et al. 2001). The *Phalaris* energy grass plantations in Sweden showed a clear increase in AM fungi, while this effect appeared to be absent at the Czech site, suggesting that site-specific responses in AM fungi may occur. Providing short rotation coppices with additional mineral nutrients might result in greater soil carbon storage and reduce pathogen attack, but results from field situations are still scarce (Rooney et al.

2009). Finally, young willow plantations appeared to have lower CO_2 emissions than Phalaris, and hence there is a need to further evaluate the environmental costs and benefits of individual biofuel crops.

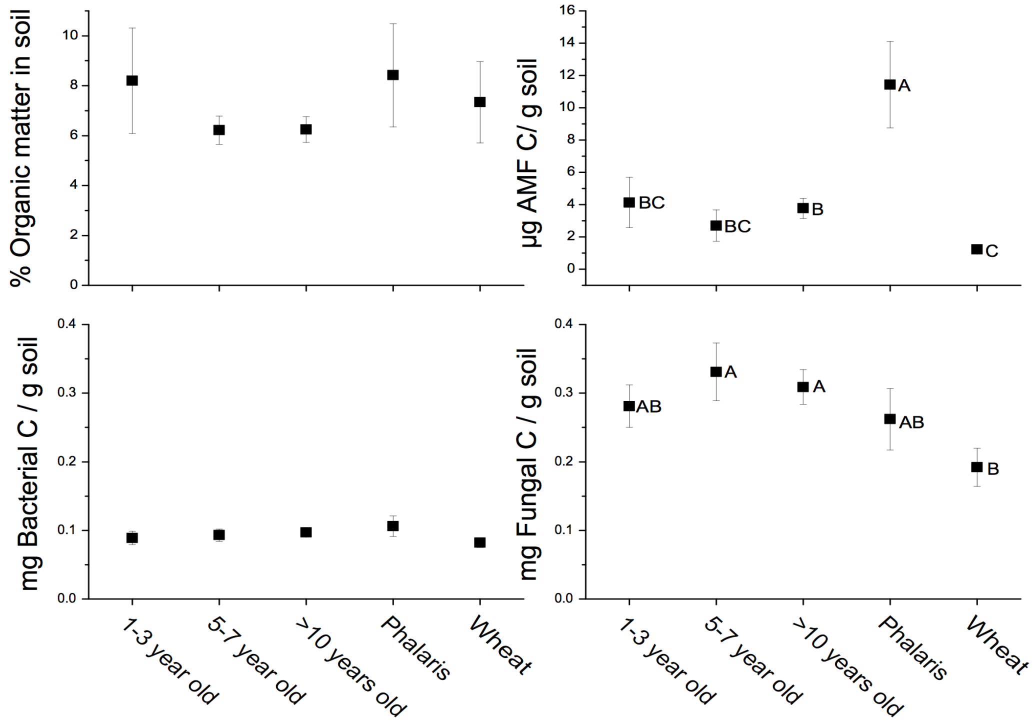


Figure 17. *Measurements of soil organic matter, mycorrhizal fungi (AMF), bacterial biomass and fungal biomass at the Swedish field site.*

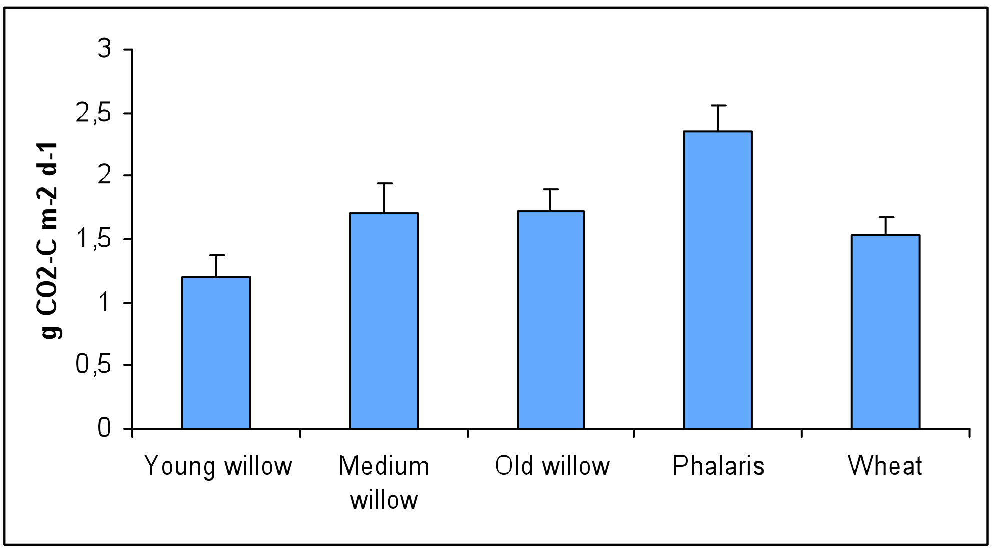


Figure 18. *Soil respiration in different biofuel crops in Sweden.*

Future land use and strategies for promoting sustainable use of soil ecosystem services

The general aims were to: i) Investigate how soil biodiversity and sustainable delivery of soil ecosystem services are influenced by changing land use regimes; as part of this work we studied land use trends in the EU and conducted a meta-analysis of the effects of agricultural practices on soil organic matter (SOM); ii) Make inferences about how land use is likely to change in the future and the implications for soil ecosystem services, which was done by evaluating existing scenarios of land use change in Europe; iii) Interact with decision makers about how to enhance sustainable use of soils: in particular a survey was posted to a random sample of arable farmers in England and Sweden to elicit their willingness to conserve soil organic matter and to adopt novel conservation measures.

Land use trends in the EU

Using data derived from Landsat images taken in 2000 and 2006 for 36 European countries, we found that the most important land use trend in Europe is the expansion of built-up areas and forests at the expense of arable land, grasslands and semi-natural vegetation. In total, land cover changed on 1.3% of the land area included in the analysis, indicating a slow-down in land use change rates compared to the period 1990–2000 (European Environment Agency (EEA) 2010). From 2007 to the present important economic developments and policy changes have occurred in Europe. For example price hikes for agricultural products and the subsequent abolishment of mandatory set-aside in 2007/2008 have led to a reduction in the area of fallow land and an increase in the area of arable crops. These changes could be expected to have an impact on the delivery of soil ecosystem services associated with former fallow land. Statistics from the Farm Accountancy Data Network's database indicate that the effects of the changing economic and policy drivers on land use change have been highly variable among EU countries. This is also the case with other land use types, where the magnitude, and sometimes even the direction of change, can differ greatly depending on the country.

The other important aspect for assessing effects of land use change on soil ecosystem services is the intensity of land management (e.g. tillage, pesticide and fertiliser use). Data on these aspects are not available for large areas; however, the empirical studies in SOILSERVICE provide evidence how intensity on soil biota and their functions. In these studies there are clear differences in soil community diversity and soil functions for different land use types; the most significant impact being a decline in diversity and ecosystem services if grassland is converted to arable land. The opposite process would be expected if arable land is converted to fallow, grassland or forest, although the building up of diverse soil communities and soil organic matter can take longer than the time it takes for the losses that occur during intensification. Although these trends have been found across regions irrespective of climatic conditions or soil types and have been reported in other studies, detailed, spatially explicit extrapolations of land use change effects are currently hampered by a lack of reference data for most regions in Europe. Monitoring systems like the one in the Netherlands with comparatively good coverage of biogeographical regions are the exception, and methodologies for fast assessments of soil communities are still in their infancy so that it seems unlikely that they will become operational in the near future (Mulder, Boit et al. 2011). Consequently impact assessments currently rely on proxies that are easily measured, which is e.g. the approach taken by the Joint Research Centre of the European Commission when they compiled a European map of threats to soils (Jeffery, Gardi et al. 2010).
Conclusions: Increasing global productivity and declining competitiveness in marginal areas are expected to lead to continued decline in the area of land under cultivation in the EU.

Effects of agricultural practices on soil organic matter

Soil organic matter (SOM) content—which is closely correlated to soil organic carbon (SOC)—is one of the major determinants of soil fertility and soil health (Williams and Petticrew 2009) and hence soil ecosystem services. The amount of SOM is influenced by processes of enormous complexity involving a high number of feedback cycles. In Europe, SOM content shows a broad latitudinal gradient, generally increasing from south to north (Jones, Hiederer et al. 2004; Smith, Smith et al. 2005). Agricultural land use is an important driver of SOM content, but its relative effects can be altered significantly by underlying physical factors (Senthilkumar, Kravchenko et al. 2009; Williams and Petticrew 2009). To determine the effects of agricultural practice (specifically, conventional vs. organic farming) on SOM, we conducted a meta-analysis of studies contained in the ISI Web of Science database for the years 1945–2009 that compared fields or experimental sites that fell into these two broadly defined categories of land management while controlling for potentially confounding factors (topography, soil types etc.). The conventional farming areas included management regimes with mineral fertilizer and/or pesticide application, whereas organic fields included management types with only organic fertilizer and no pesticides. As the methods for the determination of SOM/SOC content varied among studies and the measures for the effect of conventional vs. organic treatment were not always the same, standardized mean differences (*d*) were calculated rather than using raw differences between studies. To avoid the bias that is inherent in *d*, Hedges' *g* was calculated.

The search yielded 1476 publications for the keywords "conventional" AND "organic" AND "soil organic matter". Publication activity concerning this combination of keywords has increased steadily since 1990 and is still increasing. However, only a small fraction of the total number of publications met the screening criteria for the meta-analysis. *The meta-*analysis of effects showed a *large, positive effect of organic farming* on soil organic matter *content* (Fig. 19). The mean values of 26 out of 29 studies were at least slightly positive, and 12 of these are statistically significant based on the fact that the 95% confidence intervals do not include the zero. The summary effect has a mean value of 0.889 with p = 0.001.

Conclusions: Agricultural management practices influence soil natural capital and flows of soil ecosystem services. Intensive agricultural practices can degrade soil natural capital.

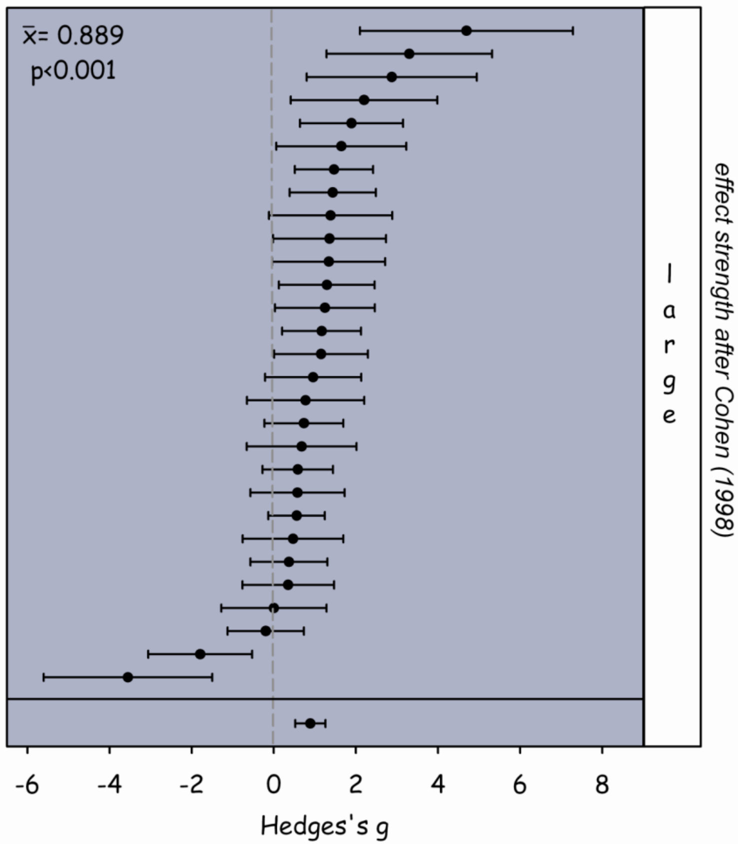


Figure 19. *Forest plot of the effect sizes (Hedges' g) of 29 studies on the effect of conventional vs. organic farming on soil organic carbon.*

Scenarios of land use change and implications for ecosystem services

A number of scenario studies concerning future land use in Europe have been conducted over the past ten years. The fundamental assumptions about the choices that societies have with respect to international integration and economic organization are primarily based on the scenarios developed by the IPCC. These are usually referred to as the 'SRES scenarios' (Nakicenovic and Swart 2000) and involve four basic *storylines* representing combinations of; *high* versus *low* levels of integration in global governance structures, and *high* versus *low* levels of regulation for environmental protection. In particular, the Scenar 2020 scenario exercise was geared towards assessing possible development pathways for rural areas in Europe (Nowicki, Weeger et al. 2007).

The quantitative output (e.g. land cover/land use) derived from the different scenario studies could not be compared directly, because the geographical areas and time frames as well as the land use/land cover types differs among them. However, we compared the general trends for different scenarios in a qualitative way. All scenarios predict roughly a continuation of current trends (see above), but with diverging pathways driven primarily by economic forces and partly influenced by policies. Increasing agricultural productivity and decreasing competitiveness in marginal areas are expected to lead to continued decline in the area of land under cultivation in the EU. Average projections for cropland area range from a reduction of ca. 5% to ca. 20% compared to the area in 2000 over time periods of 10 to 70 years into the future. Areas of grassland and permanent crops decline in all scenario exercises in which they were modelled, whereas the areas of 'abandoned grasslands/croplands' or 'surplus land' as well as urban areas, forests and areas used for biofuel production increase. It is striking that the scenario exercises imply that the decline in cropland/grassland area will over compensate the forecasted additional demand for land for biofuels (see next paragraph), so that abandonment of agricultural land would continue at a European scale. However, the outcomes for different EU member states vary widely, and land use competition might still be intense at the regional scale (e.g. for highly productive land).

The key assumptions affecting the land use scenarios are principally the future demand for agricultural products, yield per unit area of agricultural land (i.e. productivity), and relative prices of agricultural inputs and outputs. For example the increasing availability of 'surplus land' foreseen in many scenarios is directly related to assuming high rates of increase in productivity, resulting in the continued concentration of intensive agricultural production to 'favourable areas' and abandonment of agriculture and e.g. conversion to forests in marginal areas.

Projections of land use change due to increasing demand for biofuels have arrived at substantial estimates of land area requirements for biofuels. For example, implementing the target of 10% biofuel in the transport sector by 2020, according to the EU Renewable Energy Directive, would require 4.1 to 6.9 million hectares of land being dedicated to biofuel crops (Bowyer 2010). However, if the scenario projections concerning the decline in croplands and grasslands of 5% or more are realised, then the area needed for biofuel production on this scale would be available. However, these projections depend on continuing increases in productivity (e.g. yields in the EU have, on average, increased by 12% since 1995), and are based on the additional assumption that 40–50% of biofuels will be imported. Indirect land use change due to use of agricultural products for biofuel is therefore connected to great uncertainties and the environmental impacts even more so, since these cannot be calculated using the area needed for the production of energy crops alone. Rather these effects will depend very much on the type of energy crops, how they are managed and the crops/land use they replace.

Conclusions: Substantial areas of land are likely to be required for biofuels in the future, which seems to contradict the current trend of land abandonment in marginal regions of the EU. These conclusions however depend heavily on the assumption that yields will continue to increase in the future at or above historical rates. Caution should be taken because there is evidence that yields are stagnating in developed countries (Finger 2007). Finally, indirect land use change due to biofuel production and associated environmental impacts are very uncertain.

Farmers' willingness to conserve soil organic matter

Postal survey –To determine how farmers can be influenced in order to manage their soils and adopt measures to conserve soil organic matter we performed a postal survey to farmers in two countries. A four page questionnaire was mailed out to 5290 randomly selected farmers (having farms > 25 ha in size) in southern England and southern Sweden. The questionnaire comprised three parts: some contextual questions about the farm business and the farmer; a set of six questions on novel soil management options; and some questions designed to ascertain farmers' level of agreement with various statements on land and soil management issues. The response rate was 31.4% in England and 33.8% in Sweden which is quite high for postal surveys of farmers. A test for bias indicated that the response might over-represent larger farms in both countries, but in terms of farmer age it was extremely close to the national distribution. Further there are grounds to suspect that those who did not reply are more likely older farmers and those with smaller farms.

Adoption of conservation practices

Of the six soil management options presented to the farmers, the one most commonly being used on arable farms is '*returning crop residues to the land';* 87% of respondents in Sweden and 68% in England. The next most common option in use was '*operating a low tillage cultivation system'*; 42% and 57% respectively. This is followed by currently '*importing raw organic fertilisers*' on to their farms; 29% and 24% respectively. Very few respondents in either country currently operated a '*zero tillage cultivation system'*. For the remaining two soil management options, there were more noticeable inter-country differences. In Sweden only 15% of the respondents currently included '*legume break crops'* (such as peas, beans or lupins) in their arable rotation, whilst 42% in England did. As to '*using processed organic fertilisers'* on their farms such as AD digestate, compost and sewage sludge to replace inorganic nitrogen fertilizers, 11% of the respondents in Sweden currently did this as compared with 29% in England.

Let us turn now to the proportion of those currently *not* operating each of the six 'novel' soil management measures presented, who said they would be prepared to do so if they were '*paid properly'* to do so. The mean payment levels corresponding to 'paid properly' were estimated using the contingent valuation method and ranged from 75-100€/ha/year in England and Sweden (depending on the measure). For both countries, the two soil management measures that were not being carried out that were the most 'popular' for the respondents to adopt if paid properly to do so, were '*importing raw organic fertilisers'* and '*using processed organic fertilisers*'. The next most common option was '*adding a break crop'* to their rotation. The least popular option that wasn't already being practised that respondents might consider if they were paid properly to do so was '*operating a zero tillage system'*—less than 40% in both countries who were not doing this already said they would do it if paid properly.

In the final part of the questionnaire, the participants were asked to indicate their level of agreement with 22 statements on land and soil management issues. The seven levels of agreement ranged from a score of 1 equating with 'strongly disagree' through to 7 for 'strongly agree'. 'Don't know' was also an option. Table 3 summarises the five most highly agreed with statements in each of Sweden and England. Interestingly the same five statements on land and soil management were the five most highly agreed with statements in both countries, although the order varied between them. Further, note that each of these 'top five' statements was very highly agreed with by our respondents. For each country, the statement that received the lowest level of agreement was 'I will not change my land management practices unless the issues I have identified as important improve within a year'; indicating that farmers have some concern for the future, but not how far into the future it stretches.

Table 3. Level of agreement with a series of statements on land and soil management – the five most highly agreed with statements (means of level of agreement where 1 = 'strongly disagree' to 7 = 'strongly agree').

		Mean scores	
		England	**Sweden**
1.	Avoiding compaction of soil is important on my farm	6.41	6.40
2.	Spreading livestock manures on arable soil increases its organic matter content	6.35	6.50
3.	It is important to increase crop yields on my farm	6.31	6.24
4.	Chopping and returning crop residues such as straw, stems and foliage to the soil increases soil organic matter	6.24	6.44
5.	Increasing soil organic matter increases crop yield	6.23	6.41

Conclusions: Farmers are keenly aware of the importance of SOM content for crop yields (and hence indirectly soil ecosystem services) but on the same token the costs of taking conservation measures are relatively high. Nevertheless the majority of famers responding to our survey indicated they would be willing to adopt measures (even novel ones) to conserve SOM if paid properly to do so (i.e. around €90/ha/year).

Strategies for promoting sustainable land use

By virtue of provisioning ecosystem services such as crop yields being private goods, it is usual for markets to develop for these, ascribe them a concrete value (i.e. a price) and thereby inform farmers' land management decisions. Assuming that the markets are efficient, then the resulting supply of commodities should be desirable even from society's perspective (by virtue of the invisible hand). Supporting services on the other hand have the characteristic of public goods (for current and future generations), and hence 'free markets' are likely to fail to provide desirable levels because a) it is society generally who benefits from them and not farmers or b) the benefits to farmers occur too far into the future to matter to them; the problem of discounting. Instead farmers will tend to optimize current production of commodities that are priced, rather than supporting ecosystem services that are unpriced.

SOILSERVICE results indicate, generally, that managing soil organic matter will promote soil biodiversity and hence soil ecosystem services. Our interaction with farmers also indicates that this is the view held by them and that they are positive to taking measures to maintain soil organic matter/carbon if paid to do so. We therefore propose that rewarding farmers for maintaining or increasing soil organic carbon (**Carbon Payments**) would ensure cost-effective conservation of soil biodiversity, given a relevant control of carbon content. The payment could also be differentiated to reflect potential spatial variation in the value of particular soil services (e.g. nitrogen retention in regions suffering from water pollution). These payments should also be considered investment support and should decrease over time, since increasing soil carbon will boost farmers' profits in the future (Table 1). If payments based on measurements of ecosystem services (i.e. soil carbon) are infeasible then an alternative approach would be to base the policy on land use. For example inclusion of perennial grasses in the crop rotation is an effective measure to conserve and regenerate soil biodiversity. If harvested for biofuel production, they could also provide an additional income to farmers (**Biofuel Markets**).

Potential impact

SOILSERVICE has enhanced the knowledge of how soil biodiversity relates to sustainable delivery of ecosystem goods and services. The increasing need to have a more bio-based economy appears to conflict with sustainable land use. A major impact of this project will be to suggest and promote strategies for sustainable management of soil resources on a European scale, in order to mitigate degradation of soils that are under pressure from intensive land use, climate change and urbanisation. The results of this project will enhance public awareness of soil biodiversity and ways to protect and value soil biodiversity. This will enhance the commitment of the public to support sustainable use of ecosystems and to support provision of ecosystem goods and services in a sustainable way.

In the long run, global society should depend less on fossil fuel, as stocks become depleted. Moreover, the combustion of fossil fuel is enhancing concentrations of CO_2 in the atmosphere, which contributes to climate warming. Climate warming may result in increased incidence of hazards and adverse weather conditions, which may destabilize human societies. Proper management of soils and their biodiversity will also mean that society can better mitigate effects of climate change, for instance by counteracting extreme weather conditions such as drought.

Increased understanding by researchers, regional planners, and political and economic actors, including civil society organisations active in the economic sectors, is under consideration. This will be achieved through public access to information to develop inclusive management strategies that will protect or restore ecosystems and help maintain the provisions of the ecosystem services upon which economic competitiveness and welfare. Interacting with decision makers of policies and strategies to identify which ecosystem goods and services are at stake and how mitigation can enhance sustainable use of soils.

Impacts on EU-policies and strategies

SOILSERVICE envisaged to contribute to the EU-incentive of a knowledge-based economy concept by examining how loss of soil biodiversity can be prevented thereby securing sustainable use of agricultural soils, also when used for biofuel production, and by protecting and recovering natural systems and habitats. Main relevances for EU-policies and strategies are that:

- The present results can support the EU Strategy for Biofuels, which will have major implications on future common agricultural policy (CAP) and potential increase of enlarging agricultural land
- This project has addressed recommendations from work on the Thematic Strategy for Soil Protection where research is needed to underpin a future EU Framework Directive on Soils
- Identifying ecological, economical and social drivers of soil threats in the context of production of food, biofuel is essential especially in the formulation of the Common Agricultural Policy.

Impacts on European competitiveness in the area of science and technology

SOILSERVICE has:

- Brought together a multidisciplinary group of soil scientists, plant pathologists, ecological modellers and economic modellers
- Used the same technology and experimental designs, in a variety of European climatic and environmental conditions, which has enabled extrapolation of the findings beyond local or even regional conditions
- Reconciled major disciplines in ecology, which have developed in isolation from one another, especially ecosystem ecology and community ecology. This combination of approaches focussing on rigorous experimentation in field- and controlled conditions is unprecedented
- The linking of ecological food web modelling and economic modelling has been a novel approach, which enabled the valuation of biodiversity-based ecosystem services and the resulting stability and resilience for human societies.

Main dissemination activities

Dissemination of the projects findings and recommendations has been carried out at both national and EU level. At European level, we have early in the project involved and engaged with relevant contacts at the European Commission DG ENV & AGRI, JRC, also with European and national agencies (e.g. EEA), research organisations and NGOs involved in policy development relating to sustainable management of soils. A stakeholder event was organised in the final year of the project to provide an opportunity for discussion of policy recommendations resulting from the project.

Project workshops

SOILSERVICE has organised three workshops in order to focus on the issues within the project and to invite relevant policy makers and to interact with researchers. See link for more details: http://www.lu.se/soil-ecology-group/research/soilservice/workshops

SOILSSERVICE workshop Jan 2009 Wageningen The Netherlands: Soil diversity and ecosystem services how can we value services and identify threats to soil sustainability?

A multidisciplinary workshop that brought together policy- makers, economists and ecologists. In the workshop the invited speakers presented their view of three themes on the topic of how we can value ecosystem services and indentify threats to soil sustainability. See: http://www.lu.se/soil-ecology-group/research/soilservice/workshops

The workshop addressed:

- National and international policy concerning soils and conservation of nature
- Scaling and modelling the valuation of ecosystem services
- Scenarios of land use.

Workshop 1-2 February 2010, Title: Threats of Land Use Change and Urbanization on Soil Ecosystem Services

Lammi Biological Station, University of Helsinki, Finland

http://www.lu.se/soil-ecology-group/research/soilservice/workshops

Topics that were discussed

- Ecosystem services are important in cities vs. ecosystem services may hinder the economic development of cities
- Urban planners should apply ecological know-how into their practices vs. economic and other displace nature values in urban planning. Are ecosystem services more functional in densely built cities or cities with a loose structure?
- Urban soils can provide important ecosystem services for city dwellers vs. urban soils are artificial systems that have lost their ability to provide ecosystem services.
- Is it possible to enhance ecosystem services in cities? How do you do it?
- Urban biodiversity and invasive species in relation to ecosystem services –a relevant question for building sustainable cities vs. an academic exercise.

SOILSERVICE Workshop May 30- June 1 2011,
Soil biodiversity and soil ecosystem services - quantification, valuation and implementation in policies, Rauischholzhausen Castle near Giessen,
See http://www.lu.se/o.o.i.s/28497 for links to presentations and a longer description.

The third workshop of the research project SOILSERVICE was held at Rauischholzhausen Castle, an estate owned by Justus-Liebig-University. The workshop brought together 35 participants from research institutions in 10 European countries and the United States, from the European Commission and from non-governmental organizations working on issues of agriculture and soils. The working groups drafted answers to the overarching question of how the results of scientific studies can be incorporated in policies to maintain soil biodiversity and the services that soils provide to society.

Round table discussion at the European Parliament Nov 23, 2011
In the view of the ongoing CAP reform, MEP Pavel Poc (S&D) invited Soilservice and EC representatives to an expert roundtable debate
See http://www.lu.se/soil-ecology-group/research/soilservice/dissemination

Titel: Soil as natural capital: Agricultural production, soil fertility and farmers economy
Presentations were made by:

- Pavel Poc, Member of the European Parliament ENVI Committee: Opening word
- Katarina Hedlund, Lund University Sweden: Presentation of the SOILSERVICE project
- Michael Hamell, European Commission, DG ENV Head of Unit - Agriculture, Forests and Soil
- Martin Scheele, European Commission, DG AGRI Head of unit - Environment, Genetic Resources and European Innovation Partnership
- Ladislav Miko, European Commission, DG SANCO Deputy Director
- Peter Wehrheim, European Commission, DG CLIMA, Climate Finance and deforestation.

Dissemination workshop in Brussels Feb 29, 2012, at DG Environment Brussels
A stakeholder event was organised in the final year of the project to provide an opportunity for discussion of policy recommendations resulting from the project. National representatives of governmental activties and NGOs together with national and EU policymakers were invited and attended. See http://www.lu.se/soil-ecology-group/research/soilservice/dissemination

The workshop focussed on presentation of results from SOILSERVICE and ways forwards to promote further work with relevant policys. Four themes were addressed:

- Part 1: Agriculture and soil ecosystem services
- Part 2: Soil ecosystem services in the future
- Part 3: Soil ecosystem services and global change: retention of nutrients and greenhouse gases
- Part 4: Soil biodiversity and the EU soil strategy.

Exploitation of results

In all participating Member States, change of land use and intensification of land use is a key component of agricultural production and nature conservation. With the new pressure on land through biofuel production, land use intensification can be expected to increase in all EU. Furthermore, all Member States are aware of the decline in biodiversity as a result and the need for action. Such action has to be a compromise between cost-effectiveness and environmental gain. The nature of the results disseminated will be applicable to the individual Member States agri-environment/biodiversity problems, specific agri-environment schemes and contribution to the Convention on Biological Diversity. It will also be applicable to a large part to the proposed EU Soil Framework Directive and to the EU Common Agricultural Policy.

Exploitation and management of intellectual property

The results of the project will not be commercially exploitable. We have focused on exploiting results to the user community through international peer reviewed journals and on general access to the scientific community. The results will only be restricted from exploitation until they have been accepted for publication. The results and data will then be accessible to others by request only and serve policy development as well as increasing biodiversity knowledge. All general findings will be subsequently updated on the project home page, and working papers with input to EU strategies will be published on the web site, for common use. The database of the project will be maintained after the project funding period so that the results are available on request to the coordinator.

SOILSERVICE has also been presented at a number of conferences, both for the scientific community and for policymakers and other organisations. There has also been a high number dissemination activities to the general public from several of the groups. Below we have given a few examples of some of these activities.

Conferences: Presentation of Soilservice results

- EURECO, Sep 2008, Leipzig Germany: Presentaion of Soilservice and responsible for a conference workshop on ecosystem services
- ACES A Conference on ecosystem services, Dec 2008, Naples Florida US http://conference.ifas.ufl.edu/ACES/
- Integrated Assessment of Agriculture and Sustainable Development; Setting the Agenda for Science and Policy, 10 – 12 March 2009, Egmond aan Zee, The Netherlands
- Agrotica (International exhibition in the sector of agriculture), Feb 2010, Thessaloniki, Greece

- Soil, Climate Change and Biodiversity – Where do we stand? 22-24 Sep 2010, European Commission, Brussels http://ec.europa.eu/environment/soil/biodiversity_conference.htm
- 6th International Congress of European Society for Soil Conservation, 9-14 May 2011, Thessaloniki, Greece
- Nordic Symposium on Soil Zoology, Aug 2011, Lammi, Finland
- Wageningen Conference on Applied Soil Science, Sep 2011, Wageningen, The Netherlands
- Food Security:Crop Production and Resource Use, Sep 2011, Beijing, China
- Ecosystem Services, Nov 2011, Cornell University US

Public events

- Green Week, June 2010, Brussels, Belgium
- Český rozhlas Leonardo –radio broadcast, May 2010, Czech Republic
- Abels Torn- radio broad cast Aug 20211, Norway
- Waitrose Innovation Forum, Feb 2012, London, UK

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