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IMPACT ASSESSMENT

Common Agricultural Policy towards 2020

ANNEX 2B

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Annex 2B: Assessment of selected measures under the CAP for their impact on greenhouse gas emissions and removals, on resilience and on environmental status of ecosystems

The purpose of this note is to summarise the information available on the potential to reduce GHG emissions or enhance carbon sequestration of agricultural activities and on the cost-effectiveness of the measures currently being discussed or already available in the CAP. It does not address adaptation, but adaptation is covered indirectly either through win win effects of many mitigation measures or through other measures assessed in the Impact assessment.

This note does not aim to assess the full scope of the role agriculture and land use plays in mitigation. Most notably, agriculture can contribute to climate change mitigation through the provision of renewable energy and materials. A holistic analysis of these would require the consideration of emissions avoided through substitution (which generally happen in other sectors and depends on a number of factors) and the emissions associated with production for such purposes (which would require a precise knowledge of how much of agricultural production is aimed at such substitution). Such an analysis would go beyond the scope of this exercise.

It should also be noted that there are climate policy instruments dedicated to controlling greenhouse gas emissions. These include non-CO2 agricultural emissions that are already part of MS emission limits under the Effort Sharing Decision (ESD). CO_2 emissions and removals (under land use, land-use change and forestry) are not yet part of the EU GHG reduction commitment. The Commission is currently assessing whether or how such emissions and removals could be taken into account under the EU's GHG commitment. The outcome of this work may have implications on the most efficient policy mix (at EU or MS level) that could be deployed to incentivise such actions.

The note focuses first on the measures being considered as greening components of the first pillar, and then treats a selection of other relevant measures improving the GHG balance of agricultural land that can be supported under rural development. The third part of the note summarises the most relevant measures and their GHG impacts in the animal sector.

The selection of measures includes those where relevant data on effectiveness and/or costs are available and which are known to have a significant effect on mitigation.[1]

The most cost-effective set of mitigation options in agriculture varies widely from region to region as the impacts, costs and positive and negative side effects of individual measures vary depending on climatic and soil conditions and on the production systems concerned. Therefore generalisations on overall EU level costs or impacts would be highly uncertain. This note allows comparisons of the cost-effectiveness between

[1] Other measures which may be relevant for reducing agricultural emissions and/or increasing carbon sequestration include productivity increases, biochar, composting/mulching and grassland management. These have not been included in this summary either because of lack of relevant information or because they are known to have an uncertain or limited effect.

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different measures as well as relating the GHG impact to other (biodiversity, landscape…) desired impacts of the measures.

1. Greening components of the first pillar

1.1. Green cover

Description: The term ‘green cover’ is used to describe a situation where arable land which would normally be bare at certain times of the year is given a temporary plant cover so as to avoid the negative environmental effects of leaving soil bare.

Main functions of green cover are: erosion control, improvement of soil quality and soil organic matter content, flood prevention, prevention of N and pesticide and P runoff and pesticide drift and run-off.

Soils in row-crop production systems are especially vulnerable to rainfall events that occur at particular times of the year. Those times are (1) when the soil is most exposed because crops are not present or crop residues are minimal and (2) when potential pollutants in the soil system are at high levels and crops are not actively growing. The erosive impact of heavy precipitation events can be very large - These forms of erosion can cause severe and lasting damage to soil and water resources which often require costly remediation actions[2]. Green cover contributes to the mitigation of these forms of erosion, acting as a physical barrier, and to the reduction/prevention of runoff.

If the green cover is ploughed into the soil before the new crop is sown, this increases soil organic matter, with benefits for soil quality and for climate change mitigation. This is particularly significant in Mediterranean areas, where soils often have low or very low soil organic matter content (many less than 0.5% organic carbon) and are close to the threshold of soil degradation and desertification. Even small increases of soil organic matter, e.g. through the use of green cover, will take them back from this point and protect these soils[3]. Increased soil organic matter also improves soil structure, enabling the soil to fulfil other functions such as the retention of water (useful against droughts, and for flood prevention).

Cover crops constitute fast-growing crops (such as rye, buckwheat, cowpea, or vetch), which are grown either in the season during which cash crops are not grown or between the rows of some crops (e.g., fruit trees). If ploughed under as green manure it has beneficial effects to the soil and subsequent crops, though during its growth it may be grazed. Crops for green manure are usually annuals, either grasses or legumes, which are usually planted in autumn and turned under in the spring before the summer crop is sown.

Mitigation potential: Catch crops can add carbon to soils and may also extract plant-available nitrogen unused by the preceding crop, thereby reducing N_2O emissions and reducing the amount of fertiliser N that needs to be added.

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2 Conservation Implications of Climate Change: Soil Erosion and Runoff from Cropland, A report from the Soil and Water Conservation Society (USA), 2003, p. 16.

3 Soil Carbon and Organic Farming, Soil Association (UK), 2009, p. 48.

Effectiveness: The PICCMAT[4] project reviewed studies from a range of countries and therefore climatic and agricultural systems, which have reported increases in soil organic carbon (SOC) resulting from cover crops.

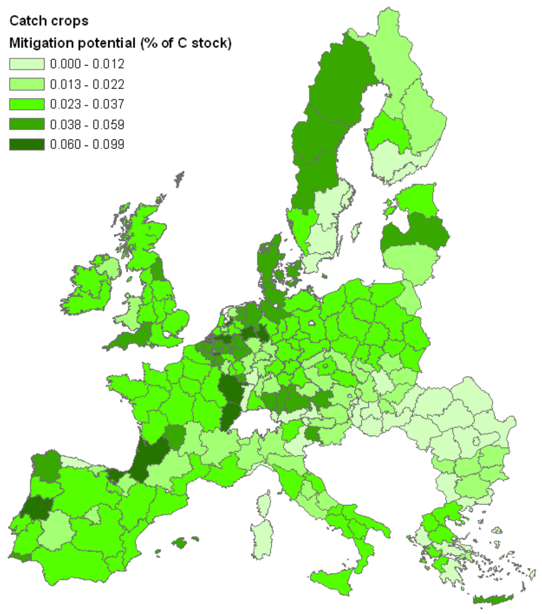
Mitigation effectiveness in t CO_2-eq per hectare and year (from PICCMAT):

	Dry climates	Moist climates
Average	0.39	0.98
Range	0.07-0.71	0.51-1.25

Major costs: Costs are low. Additional seed is needed for the catch crop, but money is saved through decreased nitrogen fertiliser requirements.

Other positive effects: Green cover acts as a physical barrier to prevent and slow down pesticide drift and run-off'. As some pesticides degrade quite quickly, this delay in their reaching water can permanently reduce their impact on the water ecosystems. In addition, green cover helps to avoid the loss of phosphorus (P) from the soil surface, so avoiding depletion of P as a nutrient, as well as avoiding water pollution by P. As well as reducing mineral fertiliser requirements, catch crops improve soil structure and nitrate adsorption, reducing N leaching (Velthof and Kuikman, 2000). Green cover can contribute to the reduction of leaching by capturing the remaining N after harvest of the preceding crop and limit N subsequent fertilization and related emissions. They have also been reported to help with pest control (Arrouays et al, 2002), and reduced fallow periods limit soil erosion, which can lead to significant loses of C, especially in winter (Petrova, 1989; Tsvetkova et al, 1995; Mihailova et al, 2001, Boehm et al, 2004).

Optimising GHG impact: The variety of benefits associated with catch crops makes them a “win-win” or “no regrets” mitigation option. A small investment in education could yield high benefits.



Source: PICCMAT

[4] http://climatechangeintelligence.baastel.be/piccmat/

1.2. Crop rotation

Description: **Crop rotation** is a planned and ordered sequence of cultivated species of different botanical families that are grown in succession on a same field. In modern EU agriculture, **most crop rotations last between 3 and 5 years**, compared to duration of 5 to 10 years in organic agriculture. They involve a succession of crops, often with a first sequence that is used to prepare and regenerate the soil (e.g. legumes or grasslands), and a second sequence that benefits from the fertility of the regenerated soil.

Effectiveness:

The aspects of crop rotations most relevant for climate change mitigation are the increase of soil organic matter, and the reduced need for N fertilisation. Enhanced crop rotations will enhance soil organic matter (SOM), and so sequester carbon – or reduce C loss from the soil. A secondary benefit of the improved SOM is that less N fertiliser needs to be added to the crops; as the production and use of N fertiliser contributes to the release of GHG, a reduction in fertiliser use is beneficial for climate change mitigation.

The effects of crop rotation vary with soil type and crops produced, farming operations and management of crop residue. 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.

Catch crops also affect emissions of N_2O in several ways: 1) reduction of N-leaching, 2) less need to apply N-fertiliser, and 3) addition of organic N to the soil.

As a mitigation measure, rotation should include crops that are beneficial for soil improvement, i.e. are fibrous rooted, high residue producing crops, for instance grass and small grains (wheat, barley, or oats). Long-term studies have shown that such management practice generates great variations of the soil carbon level and total soil nitrogen, depending on the period of the rotation. Soils have higher carbon levels in pasture lands and pasture lands which were previously cereal fields than in permanent cereal fields. Continuous leguminous cropping can increase soil carbon storage and total soil nitrogen by up to 20% in the 0-15 cm soil depth compared with rotation including cereals[5]. In contrast, large carbon *losses* from soils are likely with root crops, such as sugar beet or where almost the entire crop is removed for harvest (e.g. maize for silage production).

Perennial plants used for forage are very effective in crop rotations due to increases in organic matter and reduced soil erosion. Cover crops and double cropping systems introduced in rotation offer the same positive impacts mentioned in point 1.1.

Due to the diverse impacts, exact quantification of the mitigation effects of rotations are difficult. Examples of mitigation effects (from PICCMAT): Cereal crops with straw return increase soil organic matter whereas maize silage, potatoes and sugar beet decrease it. For a 20 year period crop rotation on average gave an increase of soil carbon equivalent to 0.7 t CO_2-eq per hectare and year (disregarding N_2O effects).

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[5] Anne Turbé, Arianna De Toni, Patricia Benito, Patrick Lavelle, Perrine Lavelle, Nuria Ruiz, Wim H. Van der Putten, Eric Labouze, and Shailendra Mudgal. Soil biodiversity: functions, threats and tools for policy makers. Bio Intelligence Service, IRD, and NIOO, Report for European Commission (DG Environment), 2010, p. 165 (http://ec.europa.eu/environment/soil/biodiversity.htm).

Major costs: Provided that machinery is available, the measure is a low cost practice that often forms the basis for other conservation practices. Generally, it increases crop rotation's productivity. Investment costs for small specialist farms in order to diversify.

Other positive effects: Although the use of **long crop rotations** has declined in recent years in European farming, they potentially **have many other agronomic, economic and environmental advantages when compared with shorter rotations and monoculture**. Major benefits include: Reduced runoff and erosion, increased organic matter, improved soil quality, controlled weeds, improved pest management by breaking disease cycles (For example, nematodes and anthracnose, the maize pest *diabrotica* can be highly susceptible to crop rotation), moisture efficiency, yields and profitability over time, improved aesthetics and wildlife habitat. In addition, rotations add diversity to farm operations and can reduce economic and environmental risks.

The agronomic benefits of rotation are due to the interactions between different crops. The crop that is cultivated first produces some modifications to the environment (especially to the soil), which can assist the growth of the crop that follows. By contrast, the simplification of cropping structure, especially monoculture, requires higher inputs to mitigate the negative effects of sequences lacking mutual support of crops.

Optimising GHG impact: The crop rotation measure needs to be refined in order to ensure mitigation benefits (e.g. by favouring legumes and other forage crops and possibly avoiding crops associated with carbon losses).

1.3. Permanent pasture

Description: The measure could entail an obligation to maintain all permanent pasture or to maintain the ratio between permanent pasture and arable land at individual farm level. Protecting permanent grassland is a priority for biodiversity policy and climate change mitigation; but its protection is also good for water quality (although less so in intensive dairy production with very high fertilizer use), flood prevention, for protecting vulnerable soils from erosion, and increasing soil organic matter**.**

Grasslands, being a mixture of different grass species, legumes and herbs, not only act as carbon sinks and to prevent erosion, but are also habitats for animals, e.g. birds and insects. Permanent grasslands act as well as a fixer for nutrients and a water regulator due to the build-up of organic matter in the soil profile.

Unlike some other land use measures where trade-offs between environmental and climate mitigation goals can make the policy choice rather complex, maintenance of permanent grassland is a win-win solution which optimises production of fodder, carbon sequestration, biodiversity and watershed protection in one go, besides the aesthetic role and recreational functions of grassland.

Environmental concerns about conversion of permanent grassland to arable land or to tree plantations are justified because of potential major impacts in terms of biodiversity loss, increase in GHG emissions, and higher erosion risks.

Main environmental functions besides climate change mitigation: biodiversity preservation, landscape conservation, erosion control, improvement of water quality and flood prevention.

Effectiveness: The conversion of grassland to cropland by ploughing entails large carbon losses. The re-conversion of cropland to grassland yields carbon sequestration effects, but these are generally assumed to be slower than the release of carbon when grasslands are ploughed (see figure 1 in annex).

Due to this asymmetry in carbon stock changes following conversion an obligation to maintain existing permanent pasture is more effective than an obligation to only maintain the amount of surface of permanent pasture at farm level, which would still allow for some conversion within the farm. Thus, a shift of responsibility for maintaining grassland surface size from the MS to individual farm level would only be effective as a GHG reduction measure if this will lead to a reduction of the total area being converted.

This asymmetry is not captured in emission inventories under UNFCCC. Most MS use rather crude estimates for emissions from land use change[6]. Carbon losses are particularly high when converting grassland on organic soils.

According to data submitted by MS to the UNFCCC, in the EU in 2008, 6.5 mio hectares were converted from grassland to cropland, and 7.6 mio hectares were converted from cropland to grassland (data for EU27 except Malta and Cyprus).

Figure 2 in the Annex indicates the distribution of soil organic matter across Europe. In regions, where general soil content is high, larger losses from conversion of grassland can occur.

Estimates of emissions/removals from land conversion in t CO_2/ha/year (example of France, Arrouays et al. 2002)

	average	range
grassland to cropland	+3.49 (emission)	+2.4-4.6 (emission)
cropland to grassland	-1.80 (removal)	-0.84-2.75 (removal)

Permanent grassland protection is crucial to maintaining and improving climate change mitigation potential in agriculture in the EU. It is one of the key land management practices helping maintain and enhance carbon levels in soils: according to data from the European Soil Database, grasslands contain about three times the quantity of C in the soil compared to arable land (8.7% in grassland and 2.8% in arable land in the top 30 cm of soil)[7]. Permanent grasslands are effective sinks for carbon, in contrast with arable land, mainly because of the build-up of organic matter in the soil profile. According to the CLIMSOIL Report[8], most grasslands in temperate regions are considered to be carbon sinks with a measured carbon sequestration rates in the range 450-800 kg C/ha/y. It is

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6 Tier 1 level of GHG reporting: Average carbon stock levels are calculated for cropland and grassland. Transition in each direction is assumed complete within 20 years.

7 Average EU-26 (no figures for Cyprus).

8 René Schils, Peter Kuikman, Jari Liski, Marcel van Oijen, Pete Smith, Jim Webb, Jukka Alm, Zoltan Somogyi, Jan van den Akker, Mike Billett, Bridget Emmett, Chris Evans, Marcus Lindner, Taru Palosuo, Patricia Bellamy, Jukka Alm, Robert Jandl and Ronald Hiederer, Review of existing information on the interrelations between soil and climate change (CLIMSOIL), Final Report to DG Environment, December 2008, pp. 59 and 63 (http://ec.europa.eu/environment/soil/review_en.htm).

estimated that the rate of carbon accumulation in the grassland soils of Europe is 670 kg C/ha/y on average, or an annual total between 1 and 45 Mt C (Smith *et al.*, 2005)[9].

Ploughing up permanent grassland is therefore highly undesirable from a climate change perspective. Even a tiny loss of 0.1% of carbon emitted into the atmosphere from European soils (all types of soils, not only grassland) is the equivalent to the carbon emission of 100 million extra cars on our roads – an increase of about half of the existing car fleet[10]. Thus, preserving existing carbon stocks in the soil and fighting the depletion of soil organic matter through improved protection of pastures and meadows are of utmost importance for our environment. When grasslands are ploughed up, one third of their carbon stock may eventually be released.

UNFCCC reporting data from MS provide an estimate of emissions and removals from land conversion. These data are, however, of limited accuracy as, for instance, most MS do not consider the asymmetry in gains and losses from land conversion. According to UNFCCC reporting, emissions from the conversion of grassland to cropland were 29.3 Mt CO_2 and removals from the conversion of cropland to grassland were -31.8 Mt CO_2. Thus, a net contribution from total land conversion between cropland and grassland was a slight sink of -2.5 Mt CO_2.

The inventories used for UNFCCC reporting need improvement, and it can be assumed that the application of higher tier levels[11] in carbon monitoring would lead to higher estimates for carbon losses. In particular, monitoring schemes have to be set up in most MS in order to better quantify areas subject to land use change and the associated emissions and removals (see for instance that, according to reported data, more than half of the conversion between cropland and grassland in the EU takes place in France, which is most likely an artefact of differences in methodology).

<u>Major costs</u>: There are opportunity costs, in particular for farms interested in re-structuring production (e.g. reducing animal numbers or switching to indoor housing). Maintenance costs are low.

<u>Other positive effects</u>: As described above, besides the climate change aspects, maintaining permanent pasture is also a key environmental measure as there are considerable benefits for biodiversity (in particular on HNV grassland), water regulation, and soil protection. Maintenance of productive permanent pasture is also key aspect of culturally valued European landscapes.

<u>Optimising GHG impact</u>: Minimising conversion of permanent grassland, except possibly in duly justified cases (e.g. re-structuration of farm); strict limitation on conversion of grasslands on organic soils. In coming years, an increase in demand for arable land at the expense of grassland seems quite likely, as this appears to be the direction of most of the major drivers – demography, an increased demand for cheap (i.e.

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9 Other estimates (Janssens *et al.*, 2003) put that value at 100 Mt C/y, but with a very large standard deviation of 133 Mt C/y.

10 IP/09/353, 5.3.2009.

11 UNFCCC permits data reporting of different quality, or "tiers". Tier 1 approaches involve the application of standard (global) emission factors multiplied with the area. For the conversion of grassland to cropland and vice versa, standard figures for carbon content are used, and it is assumed that the new content is reached gradually over 20 years. Higher tiers involve the use of emission factors adapted to the national circumstances or more advanced modelling.

intensively reared) meat in developing countries, increased demands for energy including bio-energy, as well as the loss of arable land to urbanisation. So if the present protection for permanent grassland is not strengthened, we risk seeing an increasing incidence of the ploughing up of grassland for arable uses, with all the negative environmental impacts explained above.

1.4. Ecological set-aside

Description: Set aside is land left fallow (not in production) for environmental purposes, e.g. a certain percentage of each holding.

Effectiveness:

Maintaining land uncropped can bring benefits for biodiversity[12] (more heterogeneous habitats, increase of species, habitat connectivity) for natural resources (reducing diffuse pollution by N, P and plant protection products, preventing soil erosion and improving water quality) and for climate change (reduced need for fertilisers, and increased soil organic matter, increasing water retention).

By reinforcing biodiversity, ecological set-aside will help ecosystems adapt to climate change. It will also enhance the capacity of the landscape to hold water, and so help to reduce flooding, and attenuate the effects of drought. The beneficial effects of ecological set-aside for biodiversity and other ecosystem services will be enhanced if the ecological set-aside is connected as much as possible to wider green infrastructure. The net effect on GHG will be locally variable and depend on the type of agricultural production no longer taking place on the set aside land. If farmers are free to select the area to be set aside on their farm, most likely the least productive land will be chosen, which would mean that the loss of agricultural production is likely to be below the percentage of set aside.

The overall climate change impact of set aside depends on the net effect of the different factors listed below:

- Avoided emissions from agricultural production that would have taken place on the land (fertiliser, agrochemicals, fuel, soil emissions)
- Carbon sequestration in soil and above-ground biomass on set aside land
- Emissions resulting from production of displaced production elsewhere (leakage)
- Emissions resulting from indirect land use change resulting from displaced production

As a result, the global climate impact of set aside may range from negative to positive. It is only positive if the emissions associated with the displaced production are lower than the local GHG benefits from reduced emissions and increased sequestration. This is more likely to be the case on land with high emissions per unit of production due to low productivity (as little production would be displaced per unit area) or high emissions (for instance in arable cropping on organic soils).

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[12] [12] Van Buskirk J. & Y. Willi (2004), Enhancement of Farmland Biodiversity within Set aside Land, Conservation Biology n. 18, pp. 987-994.

Mitigation effectiveness in t CO_2-eq per hectare and year (only effects on set aside land considered, leakage and indirect land-use change effects disregarded)

	Dry climate	Moist climate
Average	3.93	5.36
Range	-0.07-7.9	-0.07-3.3

As regards to indirect emissions from intensification elsewhere or from indirect land-use change, similar considerations apply as to those in relation to biofuels and bioliquids. The Commission adopted a report on this issue (COM(2010)811final), which concluded that a number of deficiencies and uncertainties associated with the modelling remain to be addressed. Nevertheless, the Commission acknowledges that indirect land-use change can have an impact on GHG emissions savings. Concluding from this report, a precise quantification of the indirect land use change induced by set aside is difficult but the effect can be significant and influences the GHG balance of the measure.

Land that is set aside should be vegetated as leaving it fallow may reduce mitigation effectiveness by 0.7 t CO_2-eq per hectare and year (Arrouays et al, 2002).

Due to the slow accumulation of soil carbon on set aside land, which can be rapidly lost following ploughing, set aside would have to be non-rotational and permanent in order to yield a meaningful carbon sequestration effect (and the same tends to apply to other benefits, such as biodiversity). From a carbon sequestration point of view, allowing either permanent pasture or revegetation with woody plants or afforestation (including the establishment of hedges) would be advantageous.

Biomass harvested from set aside land can contribute positively to climate change mitigation if used to substitute fossil sources of energy or energy intensive materials.

<u>Major costs</u>: Opportunity costs result from reduced production.

<u>Side effects</u>: Taking into account that demand for agricultural products increases globally, production no longer taking place on the set aside land will be displaced, most probably to outside the EU with associated emissions there. As a result, indirect land use changes are likely to be induced outside the EU, which can potentially exceed carbon sequestration gains on the set aside land.

It should be noted that GHG emission reduction is not the primary objective for ecological set-aside, as it is more important for water and soil protection, as well as improving habitats for biodiversity.

<u>Other positive effects</u>:

Although set-aside was introduced in 1992 as a production control management tool, it has always been recognised, including by the Commission[13], that set-aside has delivered some important environmental benefits for resource protection, farmland birds and wider biodiversity and has the potential for achieving even greater environmental benefits.

In set aside land, some natural landscape elements (e.g. bushes or grassland) can develop and if properly designed, these features can form a continuous array in the landscape thus creating green infrastructure. Set-aside has also a range of agronomic benefits such as

[13] recital 32 of Regulation 1782/2003

disease prevention and improved soil structure and fertility, increased resilience against extreme weather events. This makes that set-aside would enhance the contribution of agriculture policy to biodiversity and other environmental objectives, as well as contributing to the implementation of various environmental Directives, such as the Birds, Habitats, and Water Framework Directives.

While on the more intensive arable farms set-aside might imply a reduction in the arable land put to production of food or other commodities, there should also be benefits in terms of both shorter and longer-term economic returns from the surrounding land: ecological set-aside will assist pollinators and the natural predators of certain crop pests, and will help to increase soil organic matter and soil quality (particularly where this set-aside is rotational), all of which should be positive for farm viability. Other economic benefits could come from rural tourism especially if the set-aside had a connective pattern to it.

<u>Optimising the GHG effect:</u> A strong positive mitigation effect can be obtained from set aside if the measure is applied towards organic soils, where large emission savings can be obtained. This would, however, be difficult with an obligatory requirement for setting aside a fixed percentage on each farm.

2. Other measures related to agricultural land

2.1 Emissions from fertiliser use

2.1.1. Optimisation of fertiliser application

<u>Description</u>: In many cases, fertiliser rates can be reduced by more efficient application at the right time of the crop growth and under the most optimal weather and soil conditions, and by avoiding overdosing

Precision farming and placement gives the optimal amount of fertiliser at the right time in relation with crop growth. *Split applications* of N fertiliser can lower the emission of N_2O. Other measures related to fertiliser timing and fertiliser use under wet conditions are no application of manure during autumn (Netherlands, regulated by law) and no use of animal manure and fertiliser at the same time. Under wet conditions denitrification might take place and the danger of leaching is great in autumn. Also the emissions from crop residuals are expected to decrease.

<u>Effectiveness</u>: Using precision farming systems can lead to a reduction of 30% in fertiliser use. No fertilisation in autumn and winter might lead to a reduction of emission from crop residuals between 8 (other arable land) and 40% (sugar beet). The decrease in fertiliser depends on manure type, use of manure in spring and other variables.

The fact that less fertiliser is used leads to a decrease in energy consumption and CO_2 emissions for its production.

Mitigation potential for reduced application of fertiliser in t CO_2-eq/ha/year and costs (IIASA)

	Mitigation potential	Costs
Grassland	3.7	5-7 EUR/t
Cropland	10.2	5-7 EUR/t

Major costs: Major investment costs (e.g. 8-27 EUR per ha for a 250 ha Unit) for precision farming, and increased labour and machinery use (for split applications) which are partly balanced with reductions in fertiliser costs, and potential yield benefits.

Side effects: Reduction of fertiliser use cause fewer emissions of NH3 and lead to less nitrate leaching.

2. 1.2. Optimisation of fertiliser type

Description: The use of fertiliser with nitrification inhibitors and slow release fertilisers can decrease emissions of N_2O that result from denitrification.

Nitrification inhibitors are compounds that prevent the turnover of ammonia into nitrate. They can be applied in animal manure and fertiliser. The effect of the measure is a decrease in the use of fertiliser or a higher N uptake from the same amount of fertiliser in arable crops and grassland.

Slow release fertilisers can limit losses of nitrate and can reduce the emission factor of N_2O from fertiliser. However, the effectiveness of this measure was judged as insufficiently tested so far (PICCMAT).

Effectiveness: Apparently, GHG reductions depend on the type of inhibitor (e.g. DCD (dicyandiamide) or DMPP (3,4-dimethylpyrazole phosphate), fertiliser used (ammonium nitrate or urea) and soil conditions. GHG reductions from 26-49% were observed without effects on the crop yield for cereals and maize on a clayey loam soil. Other combinations of soil, inhibitor and fertiliser type yield lower reductions.

Major costs: Fertilisers with nitrification inhibitors and slow release fertilisers are more expensive, but if their use reduces fertiliser requirements, there might be a reduction in total costs.

Side effects: Decrease of ammonia emission and nitrate leaching.

2. 2 Soil carbon sequestration / reduction of soil carbon loss

Under most arable cropping systems, the carbon content in the soil is kept at a relatively steady (and generally very low, compared to the native vegetation) level or continues to decline over time, which causes GHG emissions. Mitigation is possible by reducing carbon losses from the soil and enhancing carbon gains, e.g. by increasing the input of organic material.

Particular attention is to be given to organic soils (peat soils) that lose large amounts of carbon under arable cultivation or drainage conditions.

Overall, there are numerous technical measures that can be beneficial for enhancing or protecting soil carbon, and these have to be fine-tuned to local conditions. The most well-known ones are summarised below.

2.2.1. Zero tillage - conservation tillage

Description: Advances in weed control methods and farm machinery now allow many crops to be grown with minimal tillage (reduced tillage) or without tillage (no-till).

Other erosion prevention measures also exist, which are not further elaborated here (e.g. contour ploughing, maintenance of terraces, etc.).

Effectiveness: According to older studies, reduced- or no-till agriculture often results in soil C gain, though this is not always the case (West & Post 2002; Ogle *et al*. 2005; Gregorich *et al*. 2005; Alvarez 2005). The mitigation potential was estimated is 0.15 - 0.70 t CO_2 eq./ha/yr (Smith et al. 2008, global average). However, more recent scientific publications shed doubt on the effectiveness of reduced tillage as a mitigation measure in general, as it tends to lead to an accumulation of organic carbon in the topsoil, whereas the lower strata may become impoverished. Most older studies only looked at the topsoil, which means that the effectiveness of this measure is possibly overstated. As the changes in the soil profile are likely to be highly specific to the soil types and management systems involved (before and after the reduced tillage regime is introduced), benefits cannot be generalised. More research would clearly be needed in the EU, not the least because most of the scientific literature on the subject originates in North America.

Carbon sequestration is not permanent. In case of re-conversion to more frequent tillage regimes, carbon can be rapidly lost again.

The reduced tillage or no-till practices also allow using less heavy machinery than for tillage, which leads to less CO_2 emissions from tractors.

Major costs: Specific machinery is required (direct seeding), which means high upfront investment costs. In regions where zero tillage can be applied without yield penalties there are costs savings from requiring less fossil fuel for machinery passes. Fuel use in conventional systems (Tebruegge, 2000; Smith *et al.*, 1998) in the UK and Germany varies from 0.046-0.053 t C ha-1 yr-1; whereas for zero-till systems, it is only 0.007-0.029 t C ha-1 yr-1 (0.007 is for direct energy use only; 0.029 includes the embodied energy in herbicides). Additional expenditure is usually needed for herbicides.

Side effects: In some cases, no-tillage can increase N_2O emissions. Weed control has to be undertaken with herbicides, and an ecological evaluation is needed.

Where soil organic carbon can be increased this generally contributes to improved soil fertility and productivity, enhanced soil biodiversity, and increased infiltration, reduced runoff and enhanced soil moisture retention, thereby reducing risk of drought and desertification.

2.2.2. *Restoration of organic soils*

Description: Organic soils constitute hotspots of emissions from agriculture, i.e. high emissions on a relatively small surface. Emissions are highest where organic soils are used for arable cropping, as this land use generally involves the most soil disturbance and drainage, but grasslands on organic soils can also have a high impact on climate change.

According to UNFCCC reported data from the MS, in 2007, cropland on organic soils occupied an area of 2.0 million hectares, which corresponded to 1.6% of total cropland. Emissions from cropland on organic soils were 37.5 Mt CO_2-eq., which corresponded to 87.6% of total emissions from cropland[14]. The surfaces of organic cropland are concentrated in a few MS with relatively large surfaces in DE, FI, SE, PL, DK and UK (more details in annex).

Many areas of organic soils in Europe which are currently used for agriculture were drained in the past and therefore have artificially reduced water tables. Measures to undo this artificial drainage, such as blocking drainage pipes, would mitigate GHG emissions and have a beneficial impact on carbon storage. The most important mitigation practice is re-establishing a high water table (Freibauer *et al*. 2004). Furthermore, emissions on drained organic soils can be reduced to some extent by practices such as avoiding row crops and tubers, and avoiding deep ploughing.

Effectiveness: The mitigation potential of organic soil restoration (including re-wetting) is estimated at 36.67 – 73.33 CO_2-eq/ha/year (Smith et al. 2008, global average). Where this measure is applied efficiently (i.e. while avoiding excessive emissions of methane), it can bring by far the greatest per hectare GHG savings of any soil related mitigation measure. Nevertheless, the effectiveness of re-wetting depends on the depth and dynamics of the water table, which influence methane and nitrous oxide emissions over time.

Peatland restoration is already being promoted in some countries. For example, in Germany some federal states are compensating farmers for restoring peatlands and setting targets of 60 % restoration by 2020, and in the federal state of Baden-Wurttemberg restoration of 50 % of cultivated peats is estimated to potentially mitigate 0.2-2.7 % of total GHG emissions from the area (Neufeldt, 2005).

Major costs: Rewetting may only require minor engineering works to block existing drains or more major land works, for example to divert water channels. If the land is used for grazing, there should be limited effect on production. However, land under arable management would usually no longer be suitable for this purpose, as the water table generally needs to be around 1.0-1.2 m below the surface for these crops (Joosten et al, 2002), requiring a change to grassland or abandonment. Novel production methods suited for restored wetlands (such as paludiculture for biomass production at potentially very high intensity) should be given more opportunities.

Other positive effects: Rewetting drained peat soils should reduce their vulnerability to physical erosion, and may also reduce losses of dissolved organic matter, via decreased rates of decomposition (Tipping et al, 1999). Biodiversity benefits are likely to be considerable.

2.2.3. *Residue management, including avoidance of burning*

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[14] Cropland remaining cropland. Land use change is not considered in these calculations.

Description: 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 it also enhances carbon returns to the soil, thereby encouraging carbon sequestration. Prohibition of residue burning (already part of GAEC).

Effectiveness: There are no good estimates for this measure overall, as carbon sequestration effects are partly offset by higher N_2O emissions. However, 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.

Estimated mitigation potential is 0.15 - 0.70 t CO_2 eq./ha/yr (Smith et al. 2008).

Major costs: Opportunity cost may occur in cases of reduced yield. Loss of potential revenues from agricultural by-products (e.g. straw). Low costs for prohibition of burning.

2.2.4 Agroforestry

Description: Agroforestry consists on increasing the number of trees on suitable agricultural lands.

Effectiveness: Trees can stock a significant amount of carbon both in the above ground part and in the roots. The mitigation potential was estimated as 0.5-10 t CO_2 eq/ha/year. (Verchot 2007).

Major costs: The planting of trees, which can be compensated by the harvest of fruits when fruit trees or the harvest of wood when the trees are mature.

Side effects: increase water retention, biodiversity and adaptation capacities, decrease erosion.

3. Animal production

The assessment below of the GHG reduction potential via measures implemented in the livestock sector is based on the results of the recently finished study "Evaluation of the livestock sector's contribution to the EU GHG emissions" (GGELS)[15]. Most of the proposed measures can be implemented and financed by RD funding.

The first part reviews the potential for GHG reductions of technical measures in the EU livestock sector and the second part quantifies the impacts of a selection of these measures using the CAPRI model. The measures presented focus on the two most "promising" areas of intervention in the livestock sector (measures on enteric fermentation and animal waste management systems, AWMS). There are large uncertainties around the indicated total mitigation potential. On the one hand, the net impact of specific abatement measures depends on the baseline climates, soil types and farm production systems; on the other, the number of studies that actually quantify GHG reductions is rather limited, both in terms of regions and mitigation measures covered.

3.1. Review of technological measures and their potential for GHG reduction

[15] December 2010; commissioned by Dg AGRI and carried out by the JRC.

Enteric Fermentation

Emissions from enteric fermentation of livestock can be reduced with actions focusing on:

- Health, maintenance and performance of the animals. To this end, diet components can be changed significantly (crude fibre, N-free extract, crude protein and ether extract) so that methane emission due to enteric fermentation might decrease. However, such actions based on overall diet efficiency of livestock may be only relevant for developing countries, as feeding regimes notable in the EU are already optimized.

- Alteration of bacterial flora, including removal of ruminant protozoa, as well as cattle breeding for minimizing methane production.

- Additives in feed are being explored towards limiting enteric fermentation. However their use is currently limited by negative effects on milk production.

- Increase of lactations per cow has the potential to reduce methane emissions by -10%, because heifers emit greenhouse gases without producing milk.

From the studies reviewed in GGELS, an indicative overall technical potential between -5% and -10% was found in measures acting on enteric fermentation.

Animal Waste Management Systems (AWMS)

This is the sub-sector with the highest potential for reduction and capable of a high contribution in terms of GHG reduction.

Composting: composting cattle manure by aerating storage containers using porous membranes and ventilation pipes reduces CH_4 emissions compared to storage as slurry (-30%) or stockpile (-70%). However the same treatment increases N_2O emissions. Another option would be collecting and burning the CH_4 emitted by the manure (Pattey et al., 2005). Furthermore, increased straw content may significantly reduce emissions during composting. In deep litter from fattening pigs, this method reduced virtually all CH_4, and N_2O emissions (Sommer et al., 2000). Composting slurry with or without other organic material and transforming the biogas into heat and/or electricity will avoid emissions of CH_4 and N_2O from storage, reducing them by up to -95%. In addition the process will decrease the CO_2 emissions by fossil fuel substitution (Mol et al., 2003).

Compaction and Coverage: Manure compacting and coverage may limit GHG emissions. For instance, cattle farmyard manure was compacted by driving over it and then covered in plastic sheeting. Comparisons to uncovered heaps confirmed reductions of CH_4, though N_2O emissions may increase depending on weather conditions (Chadwick, 2005). Covering solids storage, separated from pig slurry, considerably reduced emissions of CH_4 and N_2O, up to -80% to -90% compared to no coverage.

Temperature of storage tanks: Emissions from slurry stored inside can be reduced by moving storage tanks outside, even if temporally. For instance, storage in Scandinavian countries is at much higher temperatures compared to outside for most of the year. This will result in higher methane emissions from in-house stored slurry, and frequent removal to outside will reduce emissions, up to -35%. The same technique, i.e., taking advantage of lower outside temperatures, was successfully tested in the Netherlands.

Anaerobic digestion: Biogas production is a very efficient way to reduce GHG emissions, both via production of renewable energy and through avoidance of emissions from manure management. Technical reduction potential is about -90% for CH_4 and -30 to -50% for N_2O.

Slurry Removal from Stables: Slurry removal between fattening, in combination with cleaning the slurry pit decreases methane emission from stables of up to -40%. Of course mitigation strategies localized at housing level require further effective slurry management and treatment down the "production" chain, i.e., in order to avoid increased methane emissions afterwards, for instance in field manure applications.

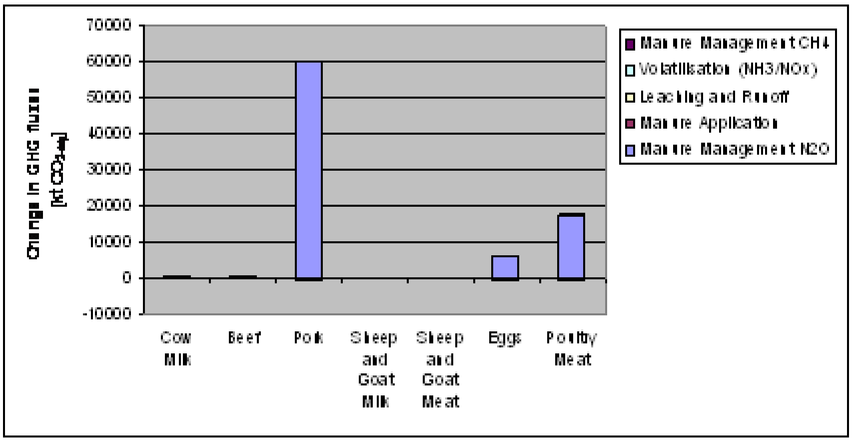
3.2. Quantification of selected measures using CAPRI

Based on estimated GHG reduction factors a quantification of the total EU level technological potential for the reduction of GHG and ammonia (NH_3) was carried out with the CAPRI model. The technical reduction potential of the measures was defined as the reduction (or increase) of emissions compared to the emissions calculated in the reference situation, if the measure would be applied on all farms. Therefore, the results must not be interpreted as estimations of the real reduction by each measure, as the implementation rates of the respective measures are unknown.

The following technological scenarios have been selected for the quantification of the emission reduction potential:

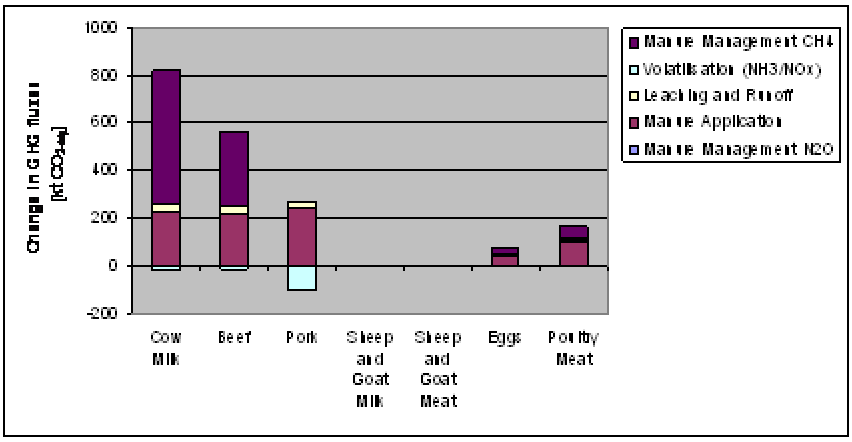
100% Animal House adaptations: Design modifications of animal houses are a possibility to reduce emissions. This can be achieved if either the surface area of the slurry or manure exposed to the air is reduced or the waste is frequently removed and placed in covered storages.

Ammonia emissions from cattle housing can be reduced through regular washing or scraping the floor, frequent removal of manure to a closed storage system and modification of floor design. For pig housing an emission reduction can be obtained by combining good floor design (partly slatted floor, metal or plastic coated slats, inclined or convex solid part of the floor) with flushing systems. In case of laying hens manure can be dried, either through the application of a manure belt with forced drying or drying the manure in a tunnel. For other poultry emissions can be reduced by regularly removing the manure using a scraper or continuously blowing heated air under a floating slatted and littered floor to dry the litter



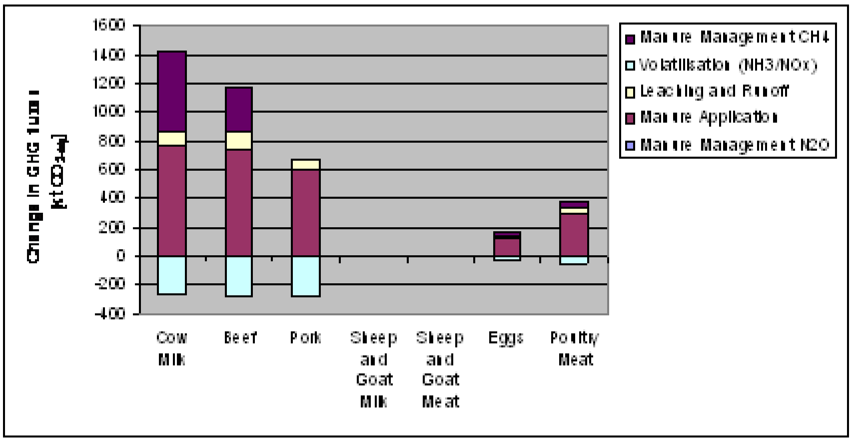
Effects on total GHG fluxes for EU-27 for the scenario '100% Animal House adaptation' in 1000 tons of CO_2-eq

<u>100% Covered outdoor storage of manure (low to medium efficiency)</u>: Low to medium efficient storage coverage systems of manure are covers of floating foils or polystyrene; high efficient coverage systems are those using tension caps, concrete, corrugated iron and polyester.



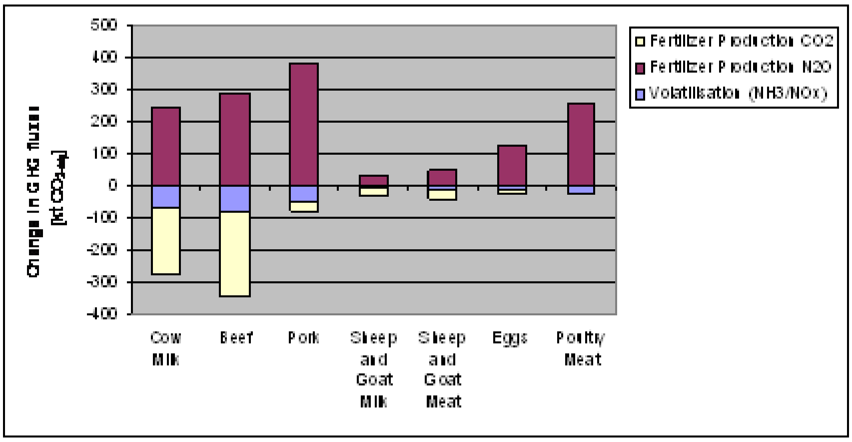
Effects on total GHG fluxes for EU-27 for the scenario '100% Covered outdoor storage of manure (low to medium efficiency)' in 1000 tons of CO_2-eq

<u>100% Covered outdoor storage of manure (high efficiency):</u>



Effects on total GHG fluxes for EU-27 for the scenario '100% Covered outdoor storage of manure (high efficiency)' in 1000 tons of CO_2-eq

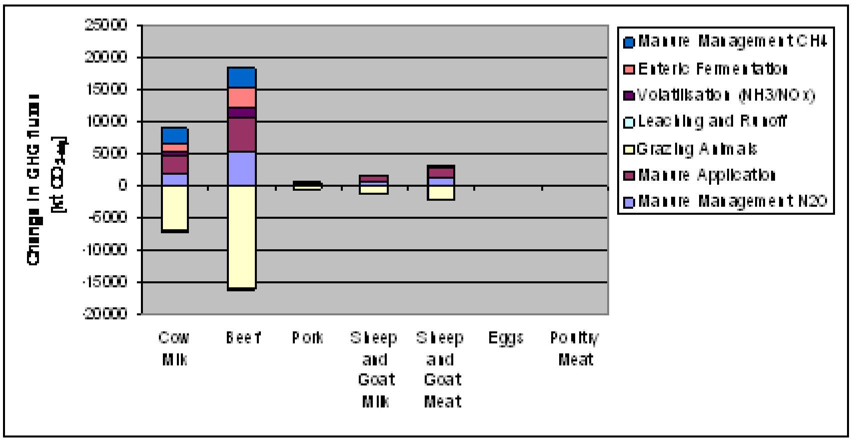
<u>Urea substitution by ammonium nitrate for mineral fertilizer application:</u> The share of N lost as ammonia is higher for urea than for other mineral fertilizers. Therefore, the substitution of urea with ammonium nitrate would reduce ammonia emissions; moreover, there is a minor effect on N_2O and CO_2 emissions from the production of mineral fertilizers and volatilized NH_3.



Effects on total GHG fluxes for EU-27 for the scenario 'Urea Substitution' in 1000 tons of CO_2-eq

<u>Reduced grazing:</u> A reduction of the grazing intensity or the time animals spend on pastures would probably reduce GHG emissions due to lower emission factors and higher carbon sequestration rates. Therefore, emissions were calculated for a scenario of zero percent grazing of animals.

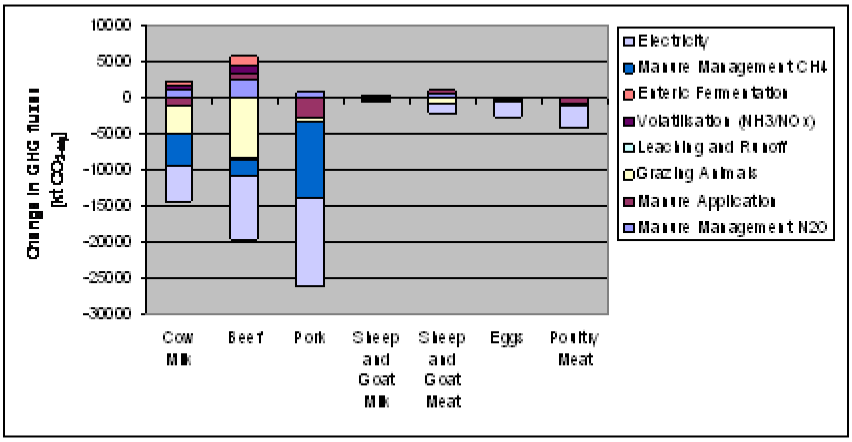
A simplistic approach for the quantification of carbon sequestration of grasslands was used, with a unique factor for all grassland, and statistics on the actual grazing intensity on European level are not available so the effect of a reduced grazing intensity cannot be quantified with the CAPRI model. Finally, it was not assessed to which degree grass consumed by grazing animals could also be harvested at a reasonable cost, and which share would have to be replaced by feed crops. For this and other reasons (animal health etc.), the scenario should rather be considered as a pure thought experiment and by no means as a recommendation for this measure.



Effects on total GHG fluxes for EU-27 for the scenario 'No Grazing of animals' in 1000 tons of CO_2-eq

As for the results, it was observed that N_2O emissions from grazing went down, while N_2O-emissions from manure management and application went up. Surprising is the increase in methane emissions from enteric fermentation, which was supposed to decrease due to the higher net energy requirement for animal activity of grazing animals. The rise in emissions is due to a lower digestibility of hay and silage compared to fresh grass directly taken up by grazing animals.

Biogas production for animal herds of more than 100 LSU (livestock units): Biogas production is one of the most efficient ways to reduce greenhouse gas emissions, by almost eliminating methane emissions from manure management, by substituting fossil energy sources and, to a lower degree, by reducing N_2O emissions from the application of the digested slurry.



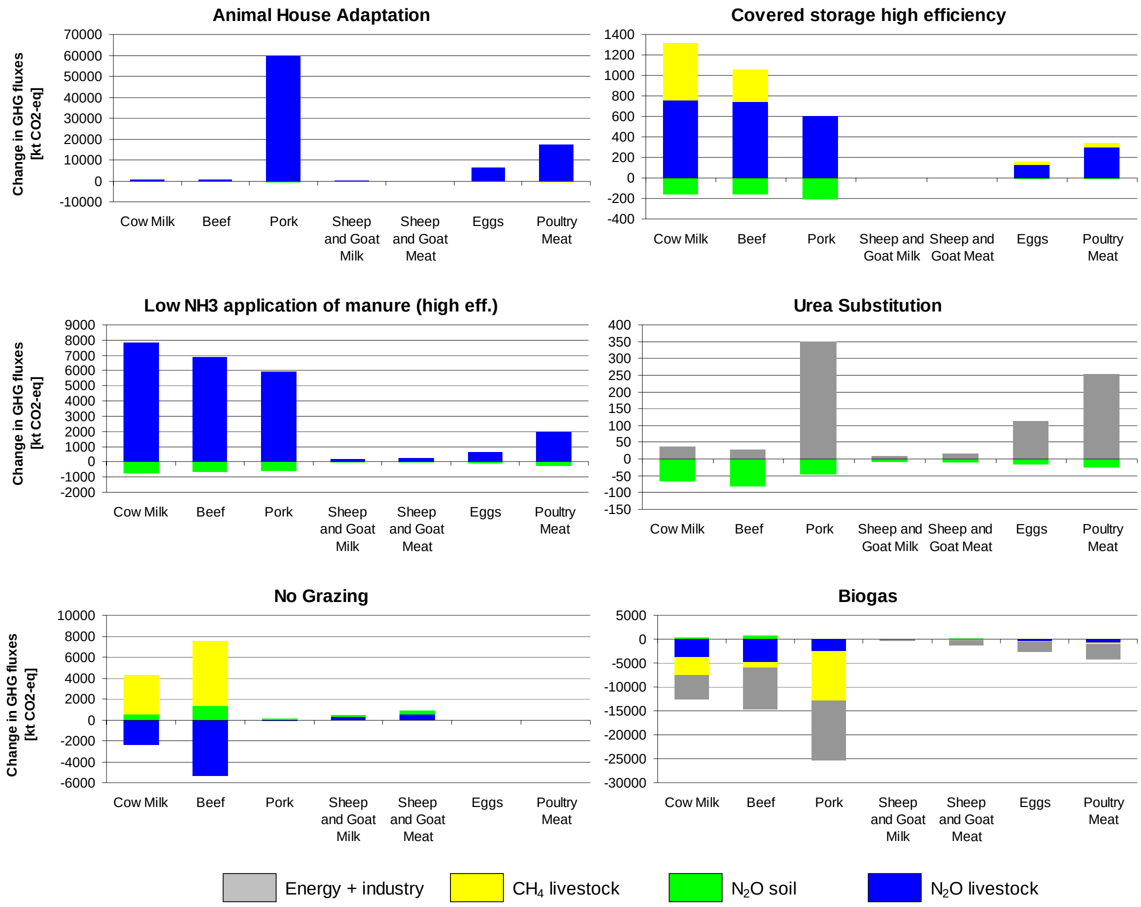
Effects on total GHG fluxes for EU-27 for the scenario ‘Biogas’ in 1000 tons of CO_2-eq

Conclusions for measures in the livestock sector

- Technological emission reduction measures are estimated to be able to reduce emissions from livestock production systems by 15-19%. This figure is for a best case scenario, assuming 100% of the farms would take up all measures above, and shows the limited mitigation potential for the livestock sector.

- Important to mention that this figure is only tentative as data for emission reductions are available mainly for ammonia (NH_3) emissions, and are associated with high uncertainty; these measures often lead to an increase of GHG emissions, for example through pollution swapping (manure management and manure application measures), or by increased emissions for fertilizer manufacturing (urea substitution).

- Despite the results presenting some reductions mainly in ammonia emissions, when combining all GHG fluxes the final result is for most of the measures limited or no reduction of emissions for the reasons explained in the previous point. Basically, only anaerobic digestion in the simulation shows positive effects with a total reduction of GHG-emissions by 60 Mt CO_2-eq across the EU where most of the reduction could be realized in beef (-14 Mio tons), cow milk (-12 Mio tons) and pork (-25 Mio tons) production. As a comparison, the recent IIASA study[16] estimates a potential reduction range for anaerobic digestion plants for liquid manure in the Pork sector of -16.6 to -34.4 Mt CO_2-eq.



[16] Potentials and costs for mitigation of non-CO2 GHG emissions in the EU until 2030. May 2010

Figure 1 - Impact of selected technological abatement measures, compared with the reference situation for the year 2004, if the measure would be applied by all farms, calculated with a cradle-to-gate life-cycle analysis with CAPRI (Source: GGELS)

It is clear that agriculture has some further possibilities to reduce its influence on climate change by reducing the emissions of methane, nitrous oxide and carbon dioxide released by farming activities and by maintaining and sequestering carbon in farmland soils. Note has to be taken that agriculture also provides an indirect contribution to emission reductions in other sectors through the supply of biomass for the production of bioenergy and renewable materials. For this part efforts made in the agricultural sector are accounted and reflected in other sectors, as only nitrous oxide and methane are reported in the agriculture inventory whilst carbon dioxide from energy use (including in agriculture) is in the energy inventory and carbon dioxide from soils in the LULUCF inventory.

Annex:

Figure 1: Carbon losses and gains resulting from land conversion

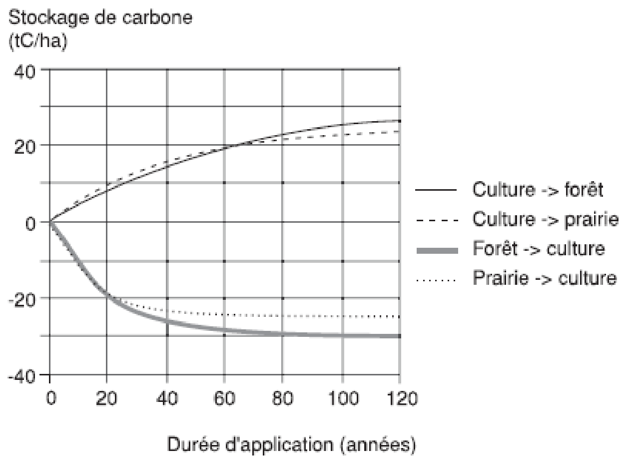


Figure 5. Evolutions du stock de carbone dans le sol associées aux pratiques provoquant les stockages (0,5 tC/ha/an durant les 20 premières années) ou les déstockages (1 tC/ha/an) extrêmes.

Il s'agit de valeurs modales pour le territoire français ; l'intervalle de confiance à 95% sur ces valeurs est de l'ordre de ±40%.

Figure 2: Distribution of soil organic content in Europe

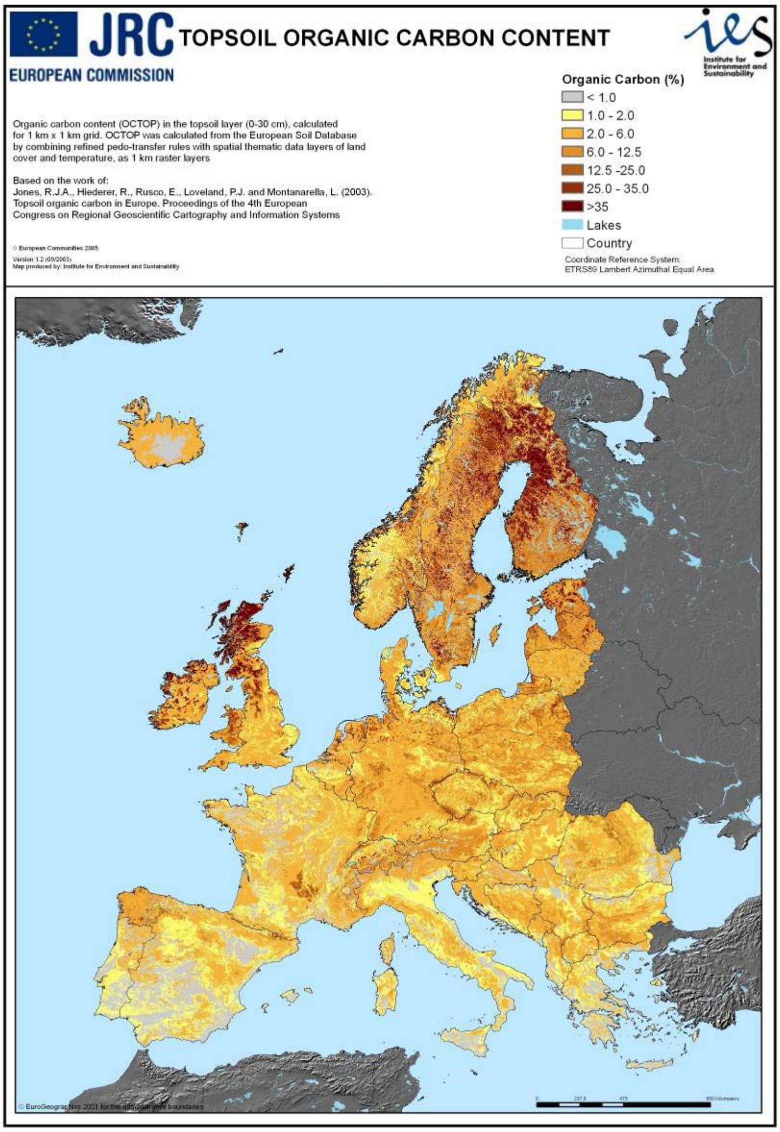


Figure 3: Land conversion between grassland and cropland (EU27 without MT and CY), based on UNF CC reporting 2008

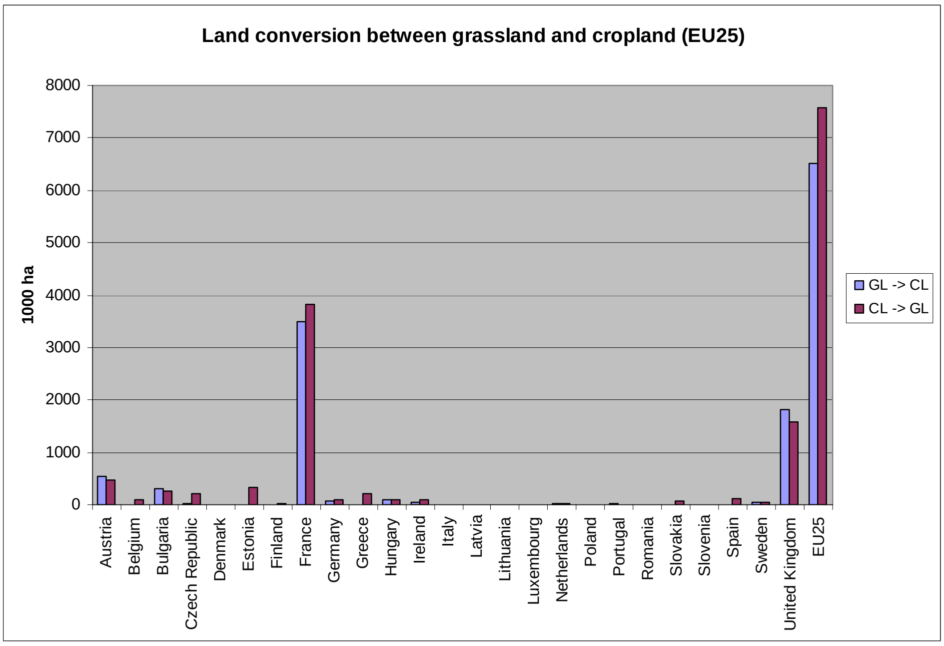


Figure 4: Emissions from conversion between grassland and cropland (EU27 without MT and CY), based on UNFCCC reporting 2008

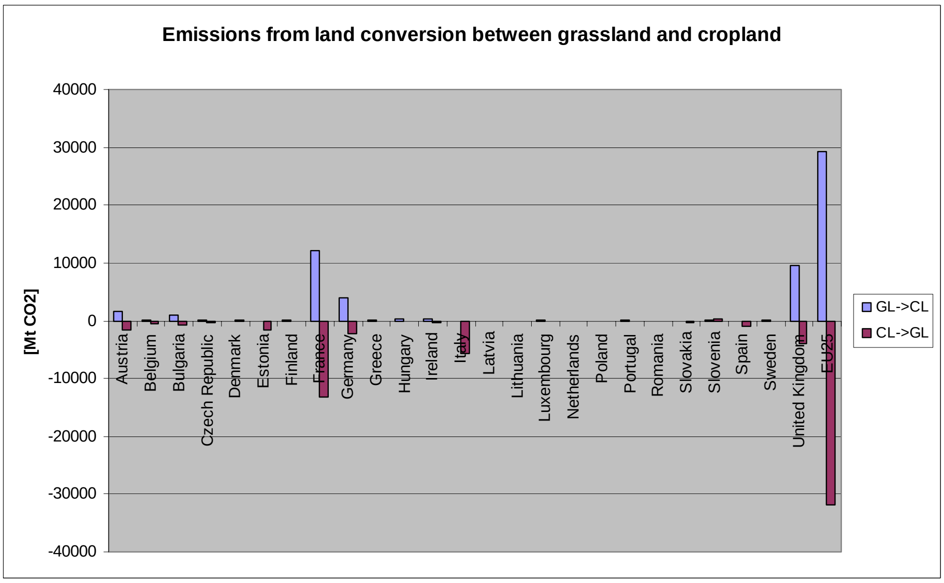


Figure 5: Surface of cropland on mineral and organic soils (EU27 without MT and CY), based on UNFCCC reporting 2008

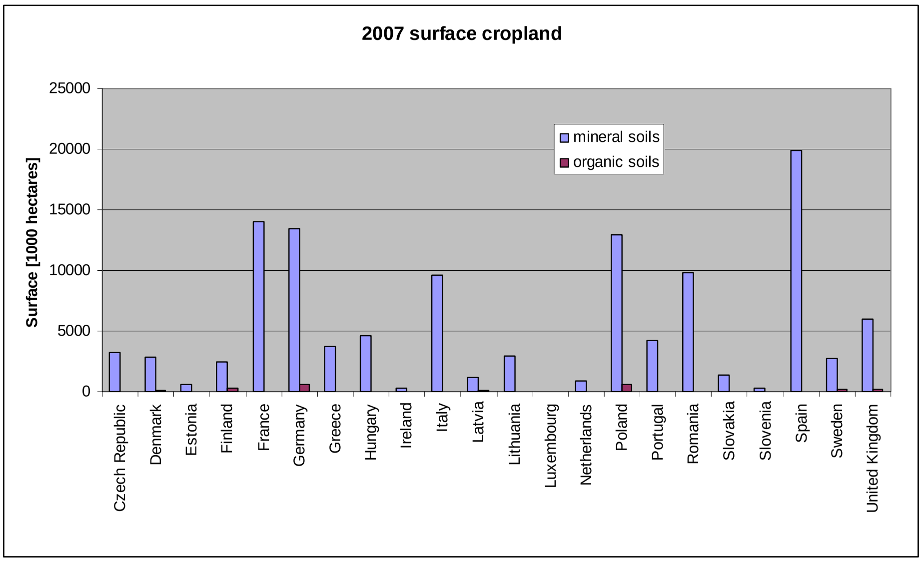


Figure 6 GHG emissions from cropland on mineral and organic soils (EU27 without Malta and Cyprus), based on UNFCCC reporting 2008

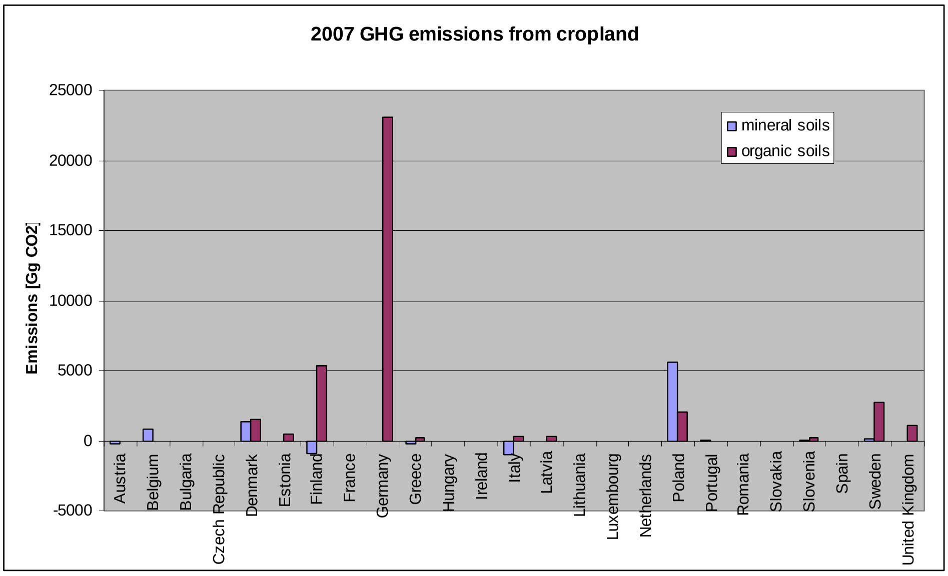


Table 1: Member States with surfaces of cropland with organic soils, based on UNFCCC reporting 2008 (reporting data are incomplete, e.g. NL did not report cropland on organic soils)

Member State	surface [1000 ha]
Germany	23127
Finland	5338
Sweden	2750
Poland	2030
Denmark	1564
United Kingdom	1129
Estonia	480
Italy	330
Latvia	308
Slovenia	244
Greece	244

Table 2: **Effect of a selection of mitigation measures on carbon sequestration in agriculture (CLIMSOIL report)**

	Potential implementtation cost	Probability of implementation*	Global mitigation potential (Smith *et al.*, 2008) (tCO_2 eq./ha/yr)
Catch crops	Low	High	0.29 - 0.88
Reduced tillage	Low	Medium (low in some areas)	0.15 - 0.70
Residue management	Low	High	0.15 - 0.70
Extensification	Medium	Low	1.69 - 3.04
Fertiliser application	No	Medium (already done in some areas)	0.26 - 0.55
Fertiliser type	Low	Medium (already done in some areas)	0.26 - 0.55
Rotation species	No	Medium	0.29 - 0.88
Adding legumes	Low	High	0.26 - 0.55
Permanent crops	Variable	Low (reduces flexibility)	1.69 - 3.04
Agroforestry	Medium	Low (reduces flexibility)	0.15 - 0.70
Grass in orchards & vineyards	Medium/high	Low	1.69 - 3.04
Optimising grazing intensity	Low / medium	Medium (already done in some areas)	0.11 - 0.81
Length and timing of grazing	Medium	Medium	0.11 - 0.81
Grassland renovation	Low	High	0.11 - 0.81
Optimising manure storage	Medium / high	Medium	
Manure application techniques	Medium	Medium	1.54 - 2.79
Application of manure to cropland versus grassland	Low	Medium	1.54 - 2.79
Organic soil restoration	Medium / high	Medium	36.67 – 73.33

* Based on potential uptake by farmers